

National Oceanic and Atmospheric Administration

User's Guide For Building and Operating Environmental Satellite Receiving Stations

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FORWARD

This User's Guide is a major update of NOAA Technical Report 44, *Educator's Guide for Building and Operating Environmental Satellite Receiving Stations*, originally published in 1989, and reprinted in 1992. There have been great changes in the technology and availability of receiving equipment as well as changes to the NOAA operated satellites. This has made a new User's Guide a necessity in keeping with the National Oceanic and Atmospheric Administration's commitment to serve the public by providing for the widest possible dissemination of information based on its research and development activities.

The environmental/weather satellite program has its origins in the early days of the U.S. Space program and is based on the cooperative efforts of the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) and their predecessor agencies.

In preparing this new *User's Guide for Building and Operating Environmental Satellite Receiving Stations*, contributions to the previous edition of Technical Report 44 and its reprint by Elva R. Bailey, R. Joe Summers, and Robert W. Popham, representatives of NOAA and NASA, are gratefully acknowledged. The author would like to thank Kelly Rindfusz of NASA's Communications Management Division, and Coleen Steele of W.T Chen & Company for some of the graphics used in this publication.

A portion of this publication is devoted to examining inexpensive methods of directly accessing environmental satellite data. This discussion cites particular items of equipment by brand name in an attempt to identify examples of readily available items. This information should not be construed to imply that these are the only sources of such items, nor an advertisement or endorsement of such items or their manufacturers. Sources for a more complete list of suppliers are cited elsewhere in the publication.

Readers of this publication requiring additional information on the application of environmental satellite data can consult Appendix B for several useful resources.

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I. INTRODUCTION

Satellites provide us with a unique and long-sought opportunity to look at Earth from space. These spacecraft now enable us to observe and measure the many forces of nature which converge on our planet. For the first time, mankind can begin to observe the global nature of the environmental factors which interact to form the complex systems we call Earth. From the unique vantage point of space, sophisticated environmental/weather satellites bring us information about cloud formations and movements, precipitation amounts, temperatures, ocean currents, sea surface temperatures, air and water pollutants, drought and floods, severe weather conditions, vegetation, insect infestations, ozone content of the atmosphere, volcano eruptions, and other factors that affect our daily lives. They have also provided us with less tangible aesthetic values which help shape attitudes about the environment of this planet. This new global attitude is, perhaps, just as important as the hard data that the satellites provide.

Much of this information is transmitted from these satellites via direct readout to ground stations where it can be displayed and analyzed. These Direct Readout Services were pioneered more than 35 years ago by the first weather satellites and have been expanded and operated in the United States by the National Oceanic and Atmospheric Administration (NOAA). The most popular of these services are the Automatic Picture Transmissions (APT) and High Resolution Picture Transmission (HRPT) of the U.S. polar orbiting satellites and Weather Facsimile (WEFAX) transmitted by the U.S. Geostationary Operational Environmental Satellites (GOES). Other countries have launched, and are now operating, weather satellites with direct readout capabilities. These include Russia, Japan, the European Space Agency, India, and China.

Thousands of direct readout stations have been purchased or built to receive the direct readout transmissions from these satellites. Government and military agencies, private industries, and a variety of private individuals including ham radio operators, students and faculty are operating ground stations. Perhaps the fastest growing use of this data is within the educational community. Many teachers with students at all levels within educational institutions have discovered the benefits of these satellites. Innovative teachers are using real time data to teach a variety of curriculum materials including the sciences, electronics, engineering, computer sciences, social studies, geography and art. Exposure to this exciting world of Earth remote sensing can help retain students, motivate them toward higher education, and expand career possibilities to areas unheard of a few years ago. This publication is designed to provide a broad spectrum of potential users with the basic information needed to establish and operate a direct readout ground station and understand the imagery provided by Earth-orbiting weather satellites.

II. DIRECT READOUT TRANSMISSIONS FROM METEOROLOGICAL SATELLITES

AN OVERVIEW

Satellite pictures received from the very early weather satellites were analyzed by U.S. Weather Bureau meteorologists, and the results, in the form of hand drawn "nephanalyses" (cloud depiction charts), were transmitted to major forecast centers throughout the United States and overseas. These charts, sent by conventional land line or radio facsimile circuits, often reached these centers too late to be of any practical value in forecasting the weather. The weather satellite direct broadcasting system, or more commonly called direct readout service, was developed to overcome this problem. Remotely sensed meteorological data are transmitted directly from polar orbiting or geostationary satellites in "real time" to forecasting centers and ground stations within signal range of the satellite. The weather satellite images were designed with a format so that they could be received and reproduced by relatively inexpensive ground station equipment, and transmitted free of charge to anyone with the appropriate receiving and display equipment.

The Direct Readout Services are an integral component of both the Polar Operational Environmental Satellites (POES) system, and the Geostationary Operational Environmental Satellites (GOES). Each of these satellite platforms can provide a high resolution and lower resolution image data product. Direct Readout Services include Automatic Picture Transmission (APT), High Resolution Picture Transmission (HRPT), and Direct Sounder Broadcasts (DSB) from the U.S. POES, and Weather Facsimile (WEFAX), and GOES I-M Variable Format (GVAR) data from the Geostationary Operational Environmental Satellites (GOES). Today, the majority of the world's users of weather satellite imagery acquire them through the use of the above direct readout systems. Over 120 countries and approximately 8,000 known (and an estimated several thousand more unknown) ground stations rely on these daily transmissions of meteorological data.

The first APT system was pioneered on TIROS-VIII (Television Infrared Observational Satellite), launched in December 1963. TIROS-VIII was one of the early polar orbiting weather satellites. Several U.S. weather offices were equipped to receive transmissions from this satellite, and plans for building relatively simple, low cost ground receiving stations were widely distributed to foreign meteorological services. By 1965, radio amateurs (hams) were designing stations for home reception and publishing design information in popular electronic magazines. Interest and activity in receiving direct readout transmissions by members of the academic community also developed. This was, in part, due to a series of articles by Professor H.R. Crane which appeared in issues of the *Physics Teacher Journal* during 1968 and 1969.

Today, polar orbiting satellites launched by the United States continue to transmit images of the Earth via APT and HRPT. These have been joined by Russian METEOR and OKEAN satellites, and the Chinese Feng Yun spacecraft, with transmission systems similar to the APT on the current United States polar orbiting satellites. This is fortunate because a ground station capable of receiving data from the U.S. polar orbiting satellites can also receive images from satellites of other countries as well.

APT FROM THE TIROS SERIES SATELLITES

APT from the polar orbiting satellites have traditionally been on radio frequencies between 137 and 138 MHz FM. As this is written in 1997, two United States satellites maintain polar orbits and transmit APT on 137.50 MHz and 137.62 MHz. The Russian polar orbiting satellites frequencies vary, but have used 137.40 and 137.85 MHz on a regular basis. The FM signal transmitted from the satellites contains a subcarrier, the video image itself, as a 2400 Hz tone which is amplitude modulated (AM) to correspond to the light and dark areas of the Earth as seen by the detecting instrument on the satellite. The louder portion of this tone represents the lighter portions of the image while the lower volumes represents the darkest areas of the image. Intermediate volumes form the shades of the grey scale needed to produce the complete image. This, then, is an analog type of data transmission.

On the latest United States Advanced-TIROS-N series satellites the APT images are produced by the primary scanning instrument called the Advanced Very High Resolution Radiometer (AVHRR). This instrument is designed to detect five channels (six channels for NOAA-15 and beyond) of radiant energy reflected from the surface of the Earth ranging from the visible spectrum, the near-infrared, and infrared spectra. Data from all of these channels are transmitted directly in high resolution digital format at high speed digital transmissions known as High Resolution Picture Transmission (HRPT). HRPT ground stations previously cost \$100,000 or more, but over the past few years technological advances have brought this price range down to well under \$10,000, making it feasible for the casual direct readout user to install an HRPT ground station.

The analog APT signal is derived from the original five (or six) channel digital data and multiplexed so that only two of the original channels appear in the APT format. This is accomplished on the satellite by using every third scan line of the digital HRPT data, produced at 360 lines per minute, to amplitude modulate a 2400 Hz tone. The scan rate of the APT signal is, therefore, 120 lines per minute (2 lines per second). The two images that appear in the APT are selected from ground control and, during daylight passes, usually consist of the visual channel and one of the infrared channels. At night, two infrared images are usually found in the APT. Therefore, the final product from APT consists of two images, side by side, representing the same view of the Earth in two different spectral bands. (See Figure II-1)

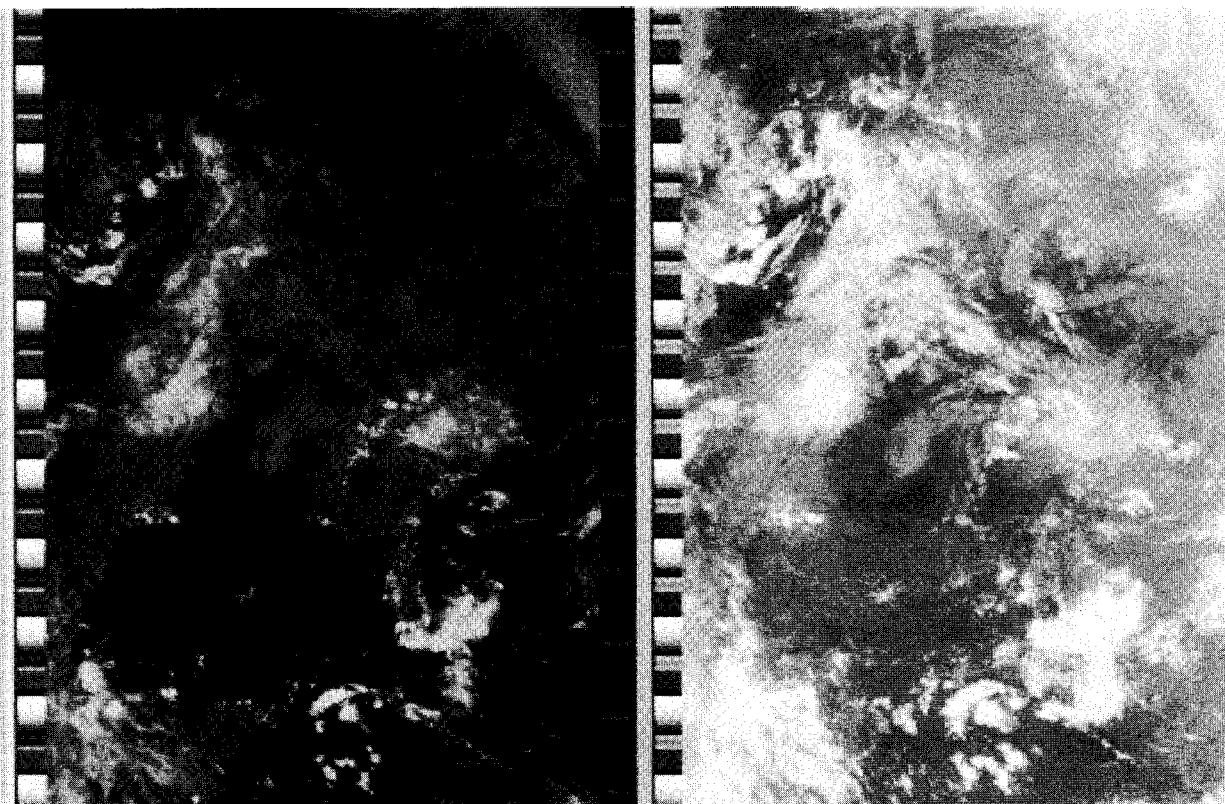


Figure II-1. APT image containing visible (left) and infrared (right) channel data

The APT signal is transmitted continuously from the satellites. This results in a strip of image as long as the transmission is received at the ground station and as wide as the scanning instrument is designed to operate at a particular altitude. Radio reception of the APT signal, however, is limited to "line of sight" from the ground station and can only be received when the polar orbiting satellite is above the horizon of a particular location. This is determined by both the altitude of the satellite and its particular path during the orbit across the ground station's reception range. At present the U.S., Chinese, and Russian polar orbiting satellites operate at altitudes between 810 and 1,200 km (488 and 744 miles). At these altitudes the maximum time of signal reception during an overhead pass is about 16 minutes. During this time a ground station can receive a picture strip equivalent to about 5,800 km (3,600 miles) along the satellite path.

WEFAX FROM THE GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITES (GOES)

WEFAX (weather facsimile) is a direct readout service provided by the GOES satellites. Similar services are transmitted from the European METEOSAT, Russian GOMS and Japanese GMS satellites. WEFAX data consists of retransmissions of processed images produced by the primary imager on the GOES satellites as well as other meteorological data and images produced by the polar orbiting satellites and relayed imagery from the European and

Japanese geostationary satellites. The format of the WEFAX signal is similar to the APT and was designed to be received and reproduced, with some modification, by low cost ground stations capable of receiving APT.

WEFAX was first tested on a geostationary Applications Technology Satellite (ATS-1) and later incorporated into the GOES satellites in 1975. The data format, using a 2400 Hz amplitude modulated subcarrier, was retained so that ground stations with display systems designed to reproduce APT could be used to also reproduce WEFAX. The radio frequency and rate of data transmission were, however, changed to 1691.0 MHz and 240 lines per minute. Therefore, APT ground stations require some modifications to receive and reproduce WEFAX. These modifications usually consist of the addition of a parabolic antenna and a down converter which can convert the 1691 MHz frequency to 137.5 MHz. The signal can then be detected by the same radio used to receive APT. The image display system must also be modified to reproduce a 240 line per minute scan rate to recreate the image. Generally, when cost is a factor in building a ground station, an APT station is installed first and the additional components for GOES WEFAX are added later.

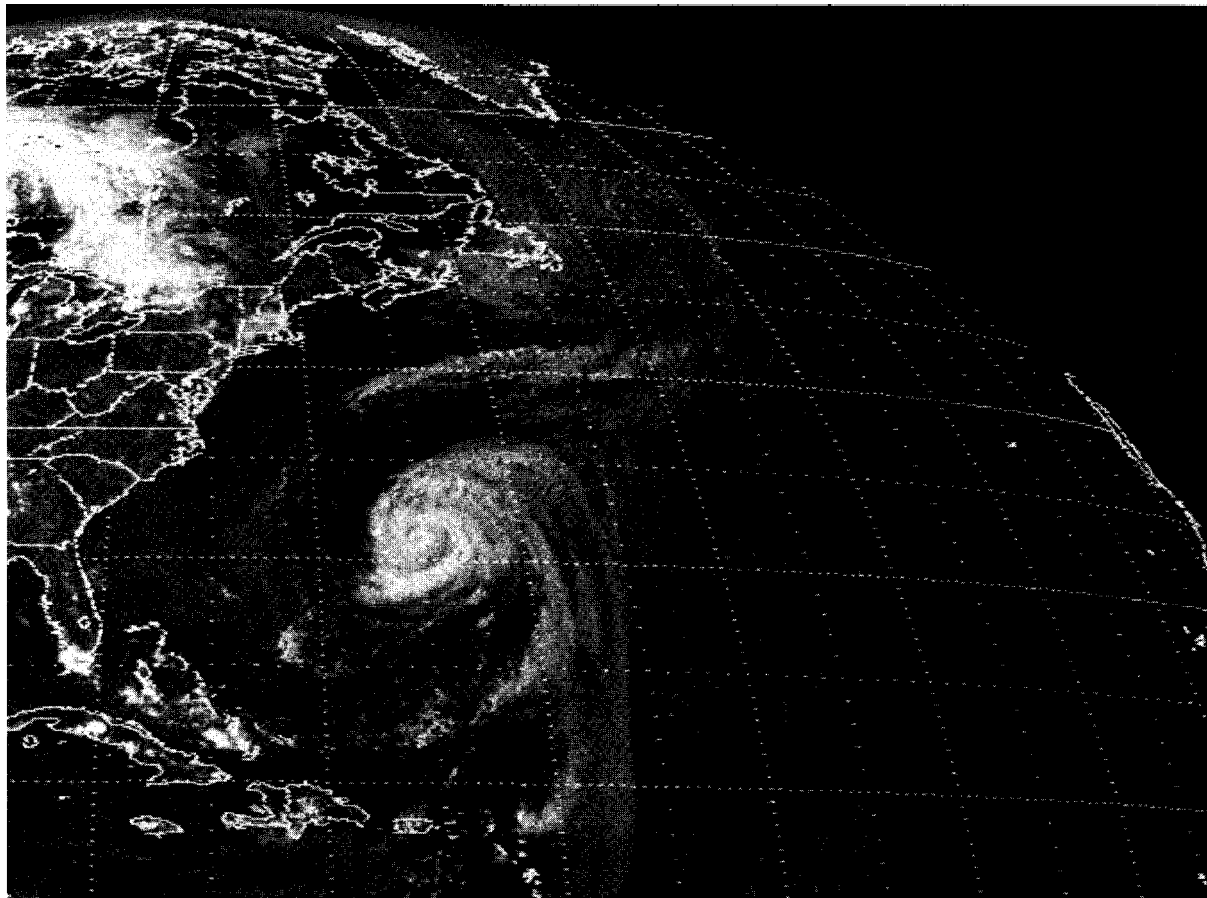


Figure II-2. GOES WEFAX Atlantic tropical sector visible image with moon (right)

The addition of WEFAX to a ground station can greatly expand the applications that are possible with a direct readout station. This is because of the large amount and variety of data that

can be obtained. In the current WEFAX schedule over 100 images can be received in a 24 hour period. These consist of scheduled data transmissions of quadrants of the full Earth disk and equatorial regions in visible and infrared spectra, composite images from the polar orbiting satellites, weather charts, ice charts, and operational messages. Figure II-2 is an example of a GOES WEFAX visible image.

HIGH RESOLUTION PICTURE TRANSMISSION FROM THE TIROS SERIES SATELLITES

The AVHRR instrument on the NOAA Advanced-TIROS polar orbiting satellites provides the High Resolution Picture Transmission (HRPT) digital imagery which is the original data from which the APT pictures are derived.

HRPT consists of five or six channels of data (depending on the satellite) in the visible, near infrared and infrared spectrum, transmitted at 360 lines per minute (LPM) at 665 kilobits per second (kbps). Due to the higher resolution of the HRPT imagery (1.1 [km. in](#) the visible band), and the additional spectral channels of information, direct readout users often prefer this data stream over the analog APT, particularly where quantitative analysis is involved.

Several vendors now provide HRPT systems in either a kit form or as an integrated ground station with a automated satellite tracking, geopolitical gridding and longitude/latitude registration, temperature calibration, scheduled ingest of data and animated loops, etc. Since the data is being output from the same instrument from which APT imagery is derived, the areal extent of coverage is essentially the same with HRPT and APT. HRPT ground stations can be assembled for under \$10,000. Figure II-3 shows an HRPT visible image of Florida.

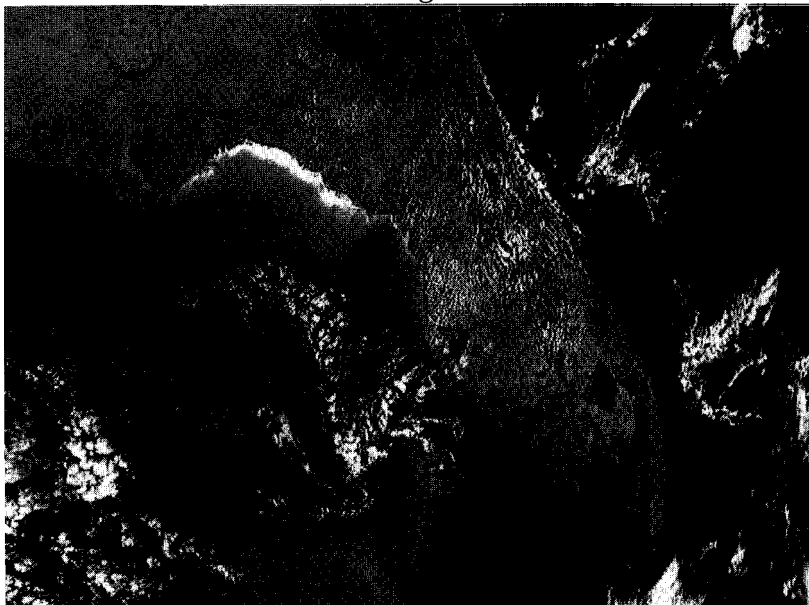


Figure II-3. HRPT visible image

HIGH RESOLUTION IMAGERY FROM THE GEOSTATIONARY SATELLITES

The latest generation of GOES satellites provide both low resolution and high resolution imagery, similar to the polar orbiting Advanced-TIROS satellites. Most direct readout users utilize the low resolution WEFAX products due to the ease of reception and display of the data. The GOES-8 and GOES-9 satellites also provide a rich source of multispectral imager and sounder data that can be applied to a multitude of meteorological and earth sciences investigations.

The Imager and Sounder on the new GOES satellites originate the raw data stream that comprises the GOES VARIABLE (GVAR) processed instrument data format. The GVAR format is used primarily to transmit high resolution (1 km. visible, 4 km. infrared) meteorological data and instrument data. Although the cost for a basic GVAR ground station is out of the reach of most casual direct readout users, many professional meteorologists, commercial and military users are benefiting from this high resolution imagery and sounder data. A complete, basic GVAR reception system can be purchased for approximately \$12,000 (in 1997).

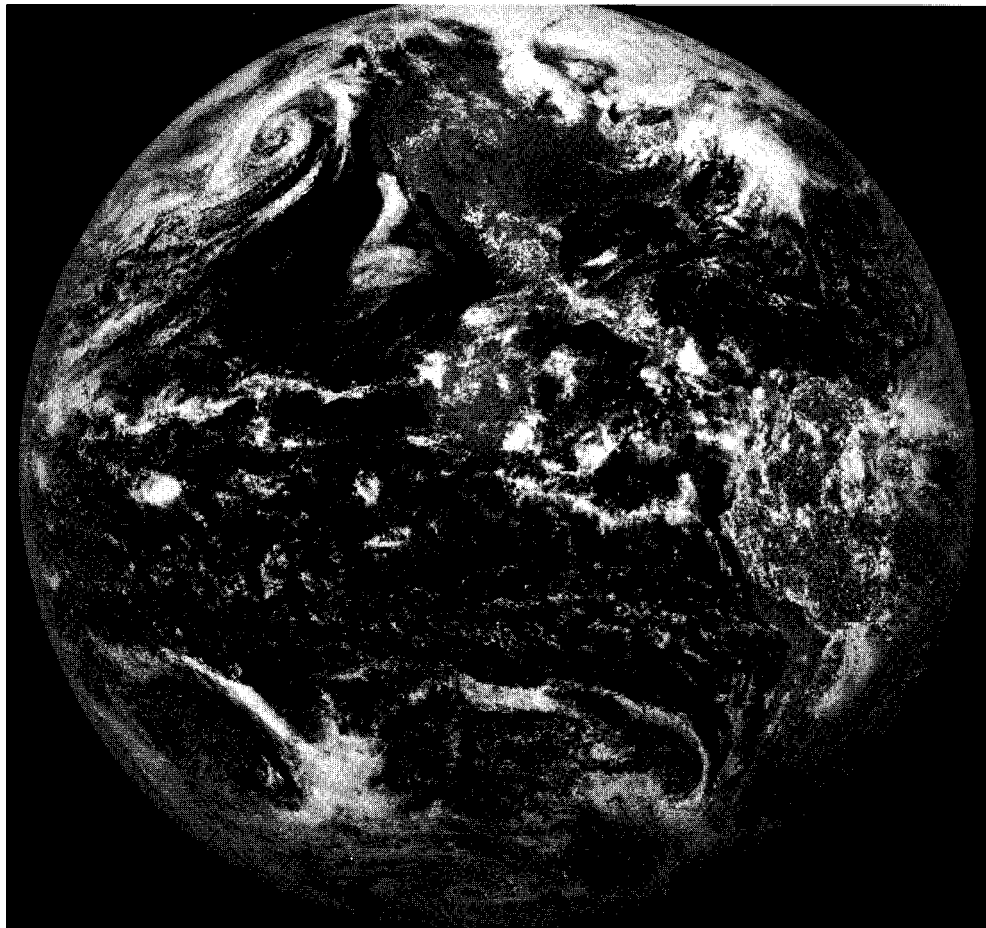
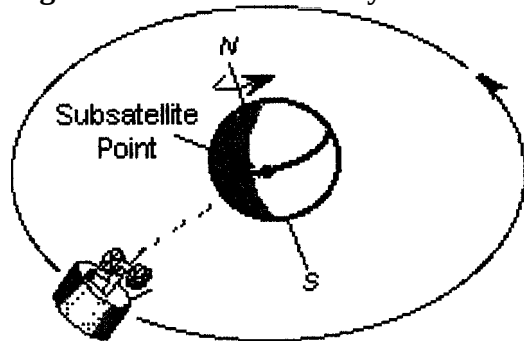


Figure II-4. **GOES-10 high resolution, full disc, visible channel image**

The United States maintains a civil and military program to provide meteorological imagery and data from spacecraft in polar and geostationary orbits around the Earth. These programs are managed by the National Oceanic and Atmospheric Administration (NOAA) and the Department of Defense, respectively. The National Environmental Satellite, Data, and Information Service (NESDIS) is a unit of NOAA and is responsible for operating the civilian weather satellites, distributing the satellite data and imagery, archiving the data, and planning for future systems. Currently, the Department of Defense also operates a constellation of polar orbiting weather satellites called Defense Meteorological Satellite Program (DMSP), and is similar to the civilian POES program. The military does not operate any geostationary weather satellites. The environmental satellites operate in two types of orbits: geostationary and polar orbiting.

Geostationary orbits are ones in which the satellite is always in the same position with respect to the rotating Earth. Orbiting at an altitude of 35,790 kilometers (22,240 miles) above the Equator, this produces an orbital period equal to the period of the rotation of the Earth (about 23 hour 56 minutes). By orbiting at the same rate of the Earth, and in the same direction, the satellite appears to be stationary (synchronous with respect to the rotation of the Earth), and therefore can provide continuous coverage over a wide-area. The U.S. typically operates a constellation of two geostationary satellites, one at 135 degrees West longitude (GOES-West), and another at 75 degrees West longitude (GOES-East). Figure 1111 shows a diagram representing a satellite in a geostationary orbit.

Figure III-1. Geostationary orbit



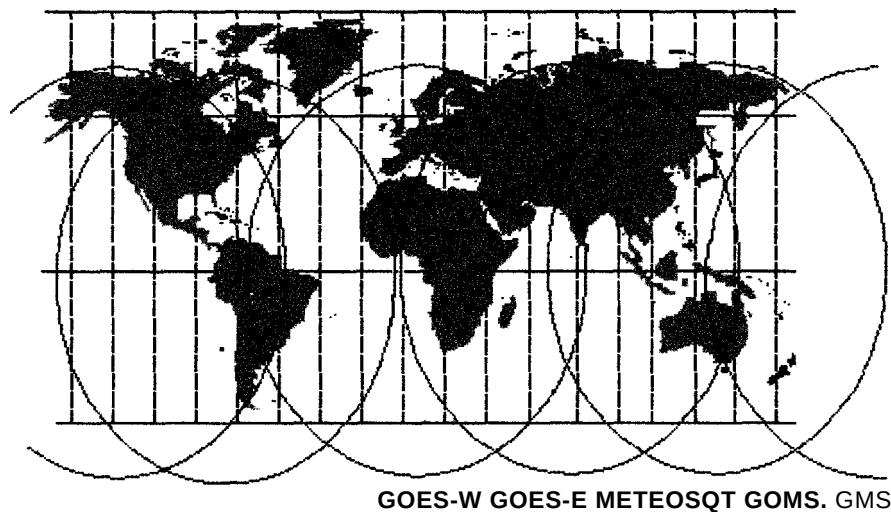


Figure 111-2. Worldwide geostationary satellite coverage

Figure 111-2 shows the coverage area for a constellation of geostationary satellites operated by the United States (GOES East and GOES West), European Space Agency (METEOSAT), Russia (GOMS) and Japan (GMS).

Polar orbiting weather satellites provide a more global view of the Earth. These satellites orbit around the poles of the Earth at an inclination to the Equator of 98 degrees (a true polar orbit has an inclination of 90 degrees), and operate in a sun-synchronous orbit. The sun-synchronous orbit provides continuous lighting of the Earth-scan view. The satellite passes the equator and each latitude at the same time every day, and therefore the satellite passes overhead at essentially the same time throughout all seasons of the year. A near-polar, sun-synchronous orbit provides regular data collection of the same area of the Earth at consistent times throughout the year. To accomplish this feat, the orbital plane of the sun-synchronous satellite must also rotate approximately one degree per day to keep pace with the Earth's surface.

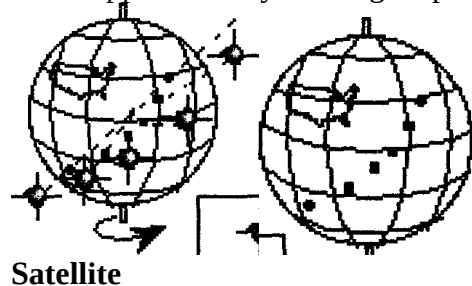


Figure 111-3. Polar orbit

Two nominal altitudes have been chosen to permit concurrent operation of two polar orbiting satellites, 833 km. (518 miles) and 870 km. (541 miles). At the 833 km. altitude, the orbital inclination is 98.74 degrees, with a period of 101.58 minutes. This results in about 14.18 orbits per day around the Earth. This orbit has a southbound Equator crossing at about 0730

local solar time (morning pass). The 870 km. orbit is inclined 98.89 degrees, has an orbital

period of 102.37 minutes, and provides 14.07 orbits per day. This is the northbound Equator crossing at about 1430 local solar time, and is the "afternoon satellite." Because the Earth rotates approximately 25.5 degrees during each orbit, the satellite observes a different portion of the Earth's surface during each successive orbit.

Figure III-3 shows the orbital characteristics of a polar orbiting satellite. Figure III-4 shows the satellite coverage of the Earth's surface for five consecutive passes during the day.

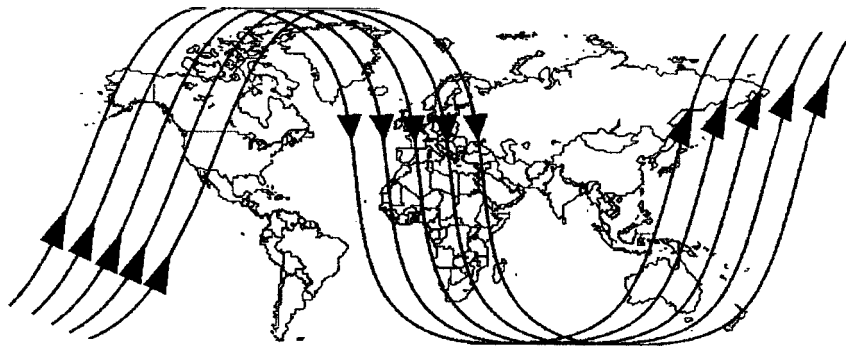


Figure III-4. Consecutive orbital tracks of a sun-synchronous polar-orbiting satellite, typical of a TIROS spacecraft

THE UNITED STATES TIROS-N SERIES POLAR ORBITING SATELLITES:

The Advanced TIROS-N (ATN) satellites, the fourth generation of United States operational environmental polar orbiting satellites, represent the current spacecraft available for receiving direct readout data. The basic operational concept of this series is to maintain two satellites in a polar orbit at all times. One will maintain an orbit so that it will pass over the ground station, traveling from north to south (descending node) during the morning. The second satellite will pass from south to north (ascending node) during the afternoon. Each of these satellites will also pass over the ground station approximately 12 hours later traveling in the opposite direction. Currently (summer 1997), the U.S. is operating NOAA-12 as the primary AM satellite and NOAA-14 as the primary PM satellite. In the U.S., the "afternoon" satellite mission is deemed as primary, with the "morning" mission providing supplementary and back-up coverage. In Europe the roles are reversed, with the "morning" mission providing the primary coverage.

SATELLITE	LAUNCH DATE	OPERATIONAL PERIOD
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TIROS-N	12 October 1978	13 October 1978 - 30 January 1980
NOAA-6	27 June 1979	27 June 1979 - 5 March 1983 and 3 July 1984 - 16 November 1986
NOAA-B	29 May 1980	Failed to achieve orbit
NOAA-7	23 June 1981	24 August 1981 - 12 June 1984
NOAA-8	28 March 1983	3 May 1983 - 12 June 1984 and 1 July 1985 - 31 October 1985
NOAA-9	12 December 1984	Placed in semi-standby mode August 1995
NOAA-10	17 September 1986	Placed in semi-standby mode December 1994
NOAA-11	24 September 1988	Placed in standby mode April 1995
NOAA-12	14 May 1991	In service (June 1997)
NOAA-13	9 August 1993	Failed 21 August 1993
NOAA-14	30 December 1994	In service (June 1997)

TABLE III-1. Launch and Operational History of the TIROS-N Series Satellites

TIROS-N, the prototype spacecraft of this series, was launched on October 13, 1978 and remained operational until January 30, 1980. The next satellites of this series were designated by letters (A, B, C, etc.) until achieving orbit at which time the letters are replaced as numbers. The first was designated NOAA-6 (NOAA-A). Table III-1 lists the launch and operational history of the TIROS-N and Advanced TIROS-N satellites.

The Advanced TIROS-N satellite was first used for the NOAA-8 mission, and all subsequent POES launches. NOAA-D (NOAA-12) was the only exception. This older satellite was taken out of storage for the 1991 launch of NOAA-12. In addition to the TIROS-N basic complement of sensors, upgraded or totally new sensors for future requirements were used in the development of the Advanced TIROS-N platform. An updated series of Advanced TIROS-N satellites, labeled NOAA K-L-M, will be launched beginning in 1998 and into the next century. Specific operating parameters of these platforms will be covered late, in Part X.

The POES satellites are three-axis stabilized orbiting platforms providing multiple sensors and data products. Primary uses include:

Provide operational coverage of the entire Earth two times per day, per satellite (with morning and afternoon equator crossings), including the 70 percent of the Earth's surface

which is water and where weather reports and current data are difficult to obtain on a timely basis.

Measure temperature and humidity in the Earth's atmosphere, cloud cover, ozone concentrations, energy budget parameters, and solar proton and electron flux near the Earth.

Receive, process and re-transmit remotely sensed data from buoys and other automated environmental stations around the world.

Relay Search And Rescue signals to rescue personnel.

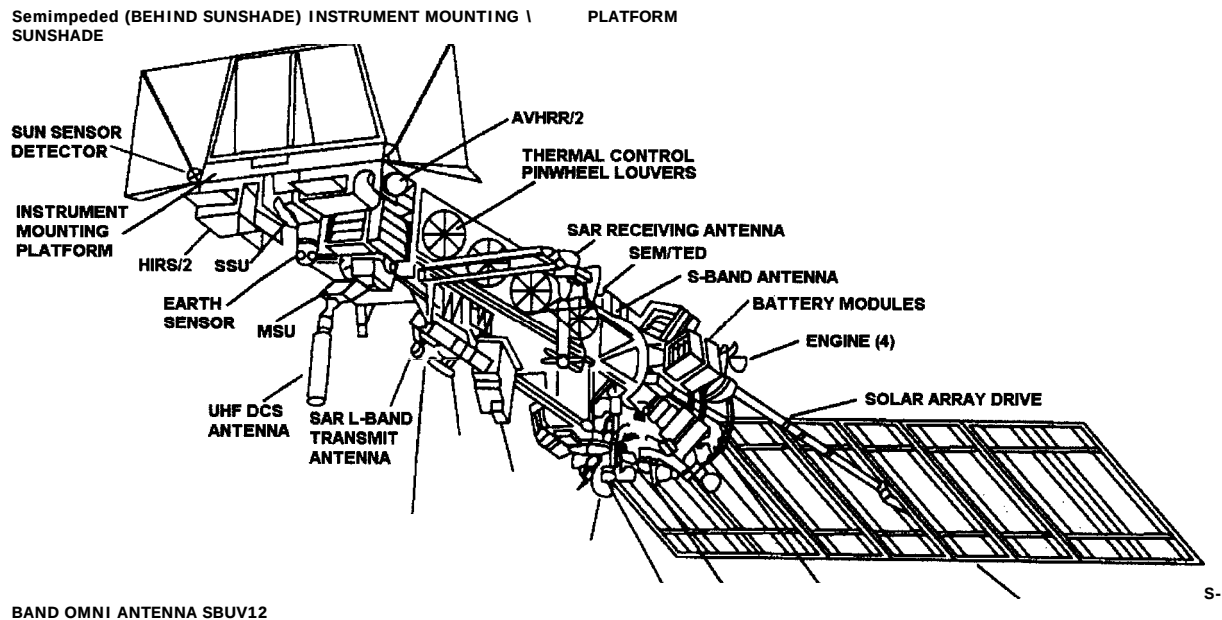
All of the TIROS satellites have been designed to carry an array of instruments to sample a variety of environmental/meteorological parameters on a global scale. Much of this data is contained in the information transmitted from the satellites in real time on specific radio frequencies, known as the Direct Readout Service. Although the primary goal of this publication is to provide information on reception, image display, and use of the Automatic Picture Transmission (APT) and High Resolution Picture Transmission (HRPT) direct readout products, it may be of interest to review all of the major missions of the TIROS satellites so that users of these satellites can get a better overall view of the capabilities of the instrumentation and products that are generated.

SPACECRAFT WEIGHT	2,288 pounds (1,030 kg)
SPACECRAFT SIZE	13.7 ft (4.18 m) long, 6.2 ft (1.88 m) diameter
SOLAR ARRAY	7.8 ft (2.37 m) X 16.1 ft (4.91 m)
COMMUNICATIONS	Command - 148.56 MHz Beacon - 136.77 and 137.77 MHz APT VHF - 137.50 and 137.62 MHz HRPT S-band - 1698, 1702.5 or 1707 MHz DCS uplink - 401.54 MHz SAR L-band downlink - 1544.5 MHz SAR uplink - 121.5, 243, 406.05 MHz
DATA PROCESSING	All digital, except analog APT
ORBIT	833 or 870 km. nominal, sun synchronous
LIFETIME	Greater than 2 years
LAUNCH VEHICLE	Atlas E/F-series

TABLE III-2. Summary of TIROS-N/NOAA E-J Satellites

Table III-2 contains a summary of general information concerning the latest, NOAA E-J, satellites. It is interesting to note that not all functions of the current satellites involve meteorological

applications. These latest satellites, known as the Advanced TIROS-N type, also carry a search and rescue instrument which is designed to aid in the location of emergency radio signals from downed aircraft and ships in distress. More information on this particular activity can be found in the Appendices.



BEACON/COMMAND ANTENNA
REACTION ENGINE (4) VHF APT S-BAND ANTENNA ANTENNA (3)
SOLAR ARRAY

Figure III-5. Diagram of typical Advanced TIROS-N spacecraft showing location of major instruments and communications components.

TIROS-N Primary Sensors:

1. Advanced Very High Resolution Radiometer (AVHRR/2)

This is a five channel scanning radiometer sensitive to visual, near infrared, and infrared spectra that is the imaging system for both the High Resolution Picture Transmissions (HRPT 1.1 km resolution) and the Automatic Picture Transmission (APT 4.0 km resolution) images that are transmitted from the spacecraft.

The AVHRR/2 provides two channels in the visible/near infrared and three channels in the infrared band. The visible and near IR channels observe vegetation, clouds, lakes, shorelines, snow and ice. The other three IR channels detect heat radiation from clouds, land, and water.

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This data can **be stored in onboard** tape recorders for later playback to NOAA's command and data acquisition stations.

The NOAA-K, L, M satellites will carry the AVHRR/3 instrument, a six-channel sensor, with the additional channel being in the near-infrared. However, only five channels of data will be transmitted at anytime in the HRPT service. APT will continue as a 2-channel service.

2. TIROS Operational Vertical Sounder (TOVS) This instrument is a three-part system to:

- a. Measure the temperature profile of the Earth's atmosphere from the surface to 10 millibars

- b. Measure the water vapor content of the Earth's atmosphere
- c. Measure the total ozone content of the Earth's atmosphere
- d. Measure the CO₂ content of the atmosphere
- e. Measure the Oxygen content of the atmosphere

The TOVS package is actually made up of three separate and independent instruments. These include the High Resolution Infrared Radiation Sounder (HIRS/2), Stratospheric Sounding Unit (SSU), and Microwave Sounding Unit (MSU).

The NOAA-K, L, M satellites will carry an improved HIRS/3 instrument while the SSU and MSU will be replaced by Advanced Microwave Sounding Units (AMSU-A and AMSU-B).

3. Space Environment Monitor (SEM)

This instrument is designed to detect radiation at various energy levels in space, measuring energetic particles emitted by the Sun including proton, alpha, and electron flux activity near the Earth.

4. Data Collection System (DCS)

This French supplied system is designed to collect data from Earth based environmental monitoring platforms. These platforms are placed in locations, some very remote, to measure various environmental parameters and can take the form of fixed installations, marine buoys, animal collars or balloons. This data is relayed to the satellite and then to ground stations for final processing. If the platform is moving, DCS can determine its position by multiple passes and the Doppler effect.

5. Solar Backscatter Ultraviolet Radiometer (SBUV)

This instrument measures the vertical distribution and total ozone in the Earth's atmosphere. These data are used for continuous monitoring of ozone distribution to estimate long term trends. SBUV is carried on spacecraft in afternoon orbits.

3-7

6. Earth Radiation Budget Experiment (ERBE)

Data gathered by this instrument package is used to study the average radiation budget of the Earth and determine the energy transport gradient from the equator to the poles. Studies of this type are used to better understand the Earth's climate.

7. Search and Rescue (SAR)

This system is designed to detect the radio signals transmitted by emergency beacon locators that are carried on ships and aircraft. The Doppler shift of these transmissions, as detected on the satellite, can be used to determine the location of the emergency transmitter. This information is forwarded to the proper authorities to aid rescue efforts.

THE UNITED STATES DEFENSE METEOROLOGICAL SATELLITE PROGRAM

The United States Department of Defense also operates a series of polar orbiting weather satellites called Defense Meteorological Satellite Program (DMSP). This is a parallel but currently a separate program to NOAA/NESDIS POES and provides high resolution weather imagery and other data to military commanders around the world

The DMSP program originated in the mid-1960s with some well-defined military objectives, including the capability to provide daily cloud-cover information, worldwide. DMSP was used for the tactical support of U.S. forces in Vietnam in the late 1960's and into the 1970's and is today used by most of the Armed Forces of the United States on a daily basis. The primary missions of DMSP are to provide:

- a. Global weather data, both visible and infrared (at a nominal resolution of 2.5 km.)
- b. Tactical weather data (at a nominal fine-mode resolution of 0.6 km.)
- c. Low-light visible data
- d. Oceanographic and solar-geophysical information

The DMSP spacecraft fly in a sun-synchronous circular orbit of 833 km. and have an orbital period of 101 minutes, with an inclination of 98.7 degrees to the Equator. Normally, two satellites comprise the constellation, traditionally with one early morning earth terminator orbit and one midmorning orbit. The DMSP operates in the direct readout mode similar to the NOAA POES.

Some of the DMSP instruments include:

1. Operational Linescan System (OLS)

The primary sensor instrument for DMSP. OLS provides high resolution (0.6 km.) daytime visible imagery, and slightly lower resolution imagery in the Infrared spectrum. This instrument provides highly-detailed information about cloud tops and synoptic weather patterns. The OLS has a unique capability to detect low levels of visible-near infrared (VNIR) radiance at night. With the OLS "VIS" band data it is possible to detect clouds illuminated by moonlight, and lights from

3-8

cities, towns, industrial sites, gas flares, and ephemeral events such as fires and lightning illuminated clouds.

2. Special Sensor Microwave Imager (SSM/I)

This instrument measures the microwave radiation from the Earth's atmosphere and surface.

3. Special Sensor Microwave Temperature Sounder (SSM/T-1)

The SSM/T-1 is used to measure vertical temperature profiles in the atmosphere.

4. Special Sensor Microwave Water Vapor Sounder (SSM/T-2)

The SSM/T-2 measures vertical water vapor profiles of the atmosphere

5. Space Environmental Sensors

A series of instruments that provides data on the geophysical environment of the upper atmosphere and ionosphere, including the charged particle activity around the spacecraft, the Earth's aurora and limb, and characterization of solar storms that may interfere with military communications around the globe.

Due to the classified nature of the DMSP imagery and other data products, the DMSP downlink data is normally encrypted, and thus the direct readout system is not currently available to nonmilitary users. However, data from the low light sensors, auroral imagery, and OLS hurricane imagery have been released to the public domain through the National Geophysical Data Center (NGDC) of NOAA. Figure III-6 is an example of the low light detection capability of the DMSP satellite and shows the incandescent lights from the cities of the U.S. taken during a nighttime pass.

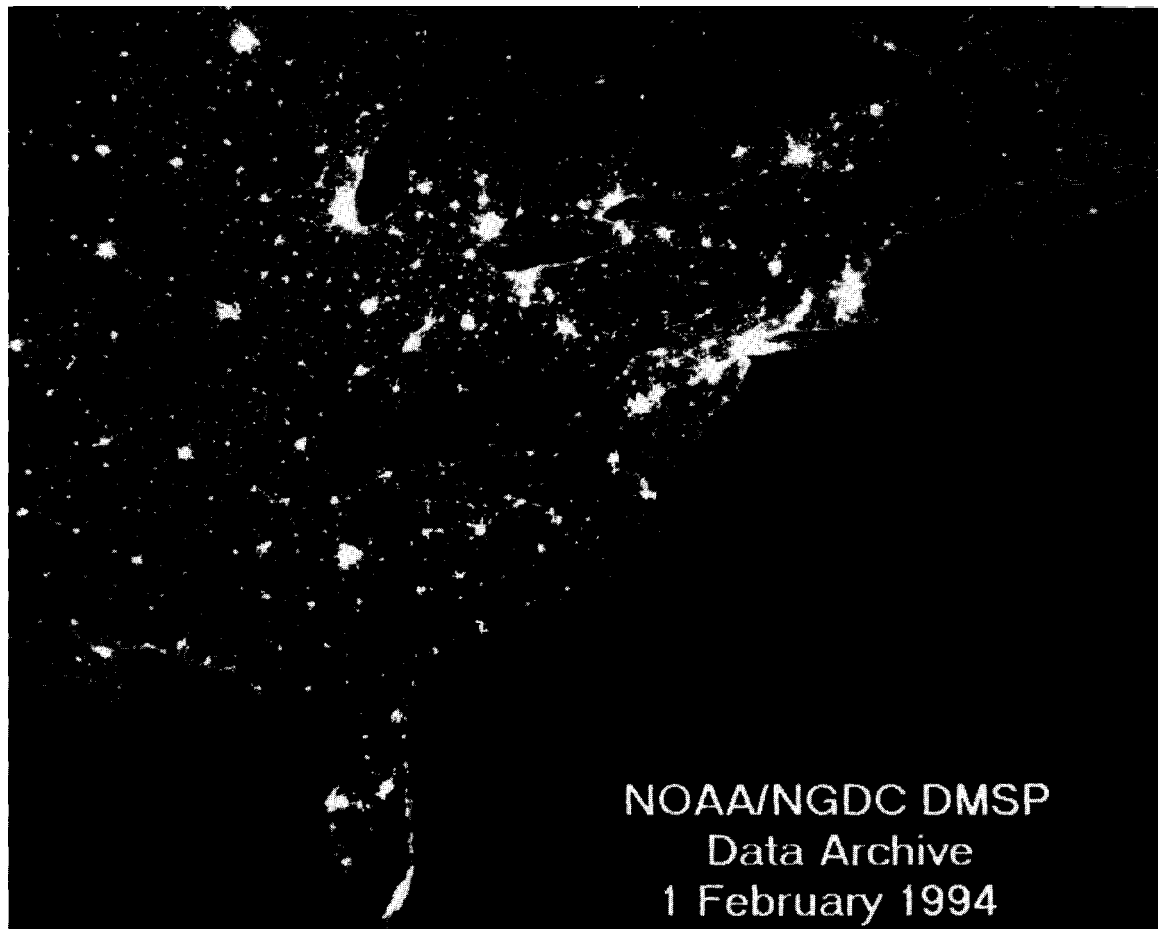


Figure III-6. Visible DMSP satellite image utilizing the OLS instrument

POLAR ORBITING WEATHER SATELLITES OF OTHER COUNTRIES

In addition to the United States, both the former Soviet Union (Russia) and the People's Republic of China own and operate polar orbiting weather satellite systems. These satellites employ direct readout systems that are compatible with the U.S. POES direct readout data products, and thus may be received by the appropriately equipped ground stations.

The Russian Satellites

The former Soviet Union developed the METEOR weather satellite system in the late 1960's. This system consisted of the space, ground and user segments which included weather satellites, receiving and processing stations, a service to control the satellite operations, and a service to predict when the satellite would be overhead. The METEOR satellites currently have

both visible and infrared Automatic Picture Transmission imagery, but no High Resolution Picture Transmission data products like the NOAA POES series.

Meteor 1 was launched on March 27, 1969, and was the first satellite identified by the Russians as part of the Meteor satellite series. Instrumentation in the first generation Meteors included television cameras and scanning radiometers. Meteor 10 (launched in December 1971) was the first Russian platform to carry the Automatic Picture Transmission (APT) system and it was nearly compatible with the U.S. NOAA TIROS modulation scheme (visible light imagery during daytime passes only).

Second generation Meteor satellites (Meteor 2-x) launches began in July 1979 and provided:

- a. twice a day information on cloud, ice, and snow in both visible and infrared
- b. twice a day global information on temperature fields and cloud heights
- c. surface water temperature measurements

The Meteor 2 spacecraft carried an optical-mechanical visible television scanner, an optical mechanical infrared television scanner, and radiometric sensors for continuous observations of near-Earth space. In general, the infrared signals from Meteor 2 satellites have been observed only during the first few weeks after launch. These images produce very low resolution cloud-cover imagery. One interesting observation is that the Meteor satellites would switch off their direct readout APT images when crossing the Earth's terminator from daylight to nighttime passes. Sensors on the satellite determined when there were insufficient light levels for the visible scanner, and shut off the transmissions until crossing the terminator once again into daylight. Thus, attempting to listen for the Russian Meteors at night was somewhat useless! Also, descending passes on winter mornings would show the spacecraft APT system to be initially off at the more northern (and hence darker) latitudes, but as the spacecraft moved further south the light levels rose to a sufficient threshold as to switch on the APT visible light transmitter. Unlike the U.S. POES constellation, the Meteor 2 series were not sun-synchronous orbits.

The third generation Meteor satellites (Meteor 3-x) made their first appearance in October 1985 with the launch of Meteor 3-1. These satellites are inserted into the same 82.5 degree inclination orbit as the Meteor 2 series, but at a greater altitude of 1,200 km. (744 miles) to prevent coverage gaps in the equatorial regions. The standard payload for Meteor 3 series is more technologically advanced compared to those carried on the Meteor 2 platforms, and consists of

- a. Scanning telephotometer for direct imaging in the 0.5-0.8 micron band with a 2,600 km. (1,612 miles) swath coverage at 1.4 km. resolution
- b. Scanning telephotometer for global coverage in the 10-12 micron band with 3,100 km. (1,922 miles) swath coverage at 3 km. resolution
- c. Scanning infrared spectrometer with ten channels in the 9.65-18.7 micron band providing 1,000 km. (620 miles) swath coverage at 42 km. (26 miles) resolution

d. Multi-channel ultraviolet spectrometer in the 0.25-0.38 micron band with 200 km. (124 miles) swath coverage at 3-5 km. resolution.

The Meteor 3-5 spacecraft has a Total Ozone Mapper Spectrometer (TOMS) which is a U.S. instrument designed to measure atmospheric ozone depletion.

Figure III-7 is a typical Meteor 3 visible image of the United States. Note the gray scale on the left and the 14 black bands which make up the "sync" pulse (data format of Meteor and U.S. POES imagery will be covered in a following section).

The Russian Meteor series satellites usually transmit in the VHF radio spectrum at 137.400 MHz and 137.850 MHz, but 137.300 MHz has also been used in the past.

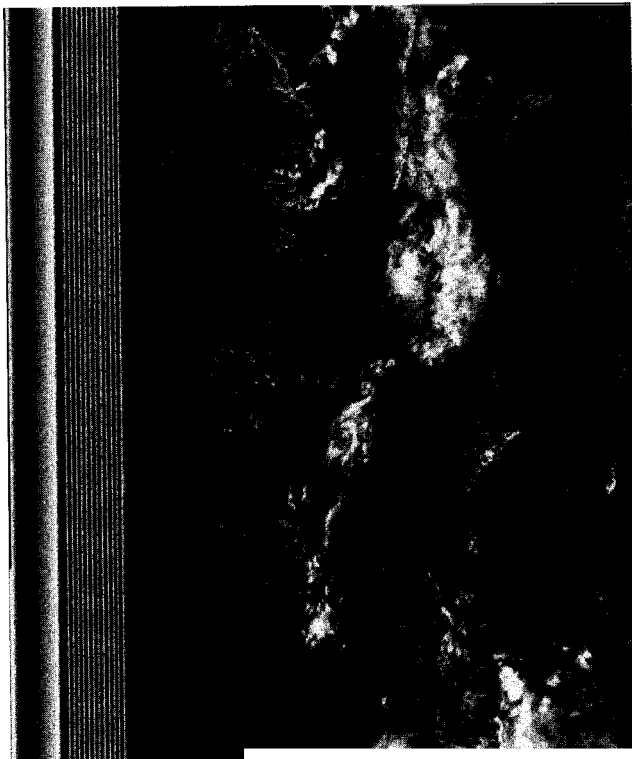


Figure III-7

Other Russian Direct Readout Satellites

Russia operates other remote sensing satellites that have direct readout imagery capable of being received with the same equipment used for the NOAA POES. Two of these satellites are the OKEAN and SICH series. In the late 1970's, the former Soviet Union began testing a new series of instruments that would complement the standard meteorological payloads and also provide information on the oceans and ice conditions. After testing various remote sensing equipment on four test launches during 1979-81, the first prototype OKEAN satellite was orbited in 1983, and had a code designation of Cosmos 1500. This satellite was followed by three other Cosmos prototype launches. The first operational OKEAN was launched in 1988.

The OKEAN satellites are a series of oceanographic remote sensing satellites, with payloads including:

- Synthetic Aperture Radar (SAR)
- Microwave Radiometer/Sounder Medium and high multi spectral scanner
- Visible APT-like imagery (3 channels) with 200 meter (660 feet) resolution
- Infrared APT imagery (3 channels) with 600 meter (1,980 feet) resolution

The OKEAN platforms have the following direct readout missions:

- All-weather monitoring of sea-ice conditions on rivers and oceans
- All-weather monitoring of seaway, storm, and cyclone regions
- Radar and optical monitoring of ocean surfaces

The direct readout imagery that may be received from the OKEAN satellites usually contains purely visible, or a mix of visible, infrared, and synthetic aperture radar pictures. SICH is a newer series of oceanographic satellites very similar to the OKEAN series. SICH also transmits visible, infrared, and SAR imagery. Both OKEAN and SICH direct readout imagery may be received on 137.400 MHz.

The Chinese Weather Satellites

The People's Republic of China began its meteorological satellite program in the late 1960's. Their program consists of both polar orbiting and a geostationary satellite development phase. To date, China has launched two polar orbiting weather satellites that have a direct readout capability fully compatible with the NOAA POES. Feng Yun (FY-1A) (Wind and Cloud) was launched September 7, 1988. It carried an Advanced Very High Resolution Radiometer (AVHRR) with five spectral channels and disseminated the data in three modes: HRPT, APT, and Delayed Picture Transmission (DPT). The direct readout capability of this satellite looked very similar to the NOAA POES satellites. Due to problems with the attitude control system the satellite went out of control after 39 days in orbit. Feng Yun B (FY-1B) was launched on September 3, 1990. It carried a similar AVHRR instrument, and provided excellent HRPT, APT, and DPT imagery until this satellite also lost attitude control capability shortly after launch. Both FY-1A and FY-1B were launched into near polar orbits at an altitude of 870 km. and were inclined at 98.8 degrees to the equator. The Automatic Picture Transmission direct readout was transmitted at 137.795 MHz.

A third Chinese polar orbiter (FY-1C) is currently in construction and is expected to be launched in the 1997-1998 time frame. FY-1C will carry a Multi spectral Visible and Infrared Scan Radiometer (MVISR) which is an updated sensor from FY-1A and FY-1B. Orbital parameters and operating frequencies for the HRPT and APT imagery will be similar to the FY-1A and FY-1B platforms.

The European Weather Satellites

Beginning in 2002, the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) will launch their first polar orbiting meteorological satellite, METOP-1. It will carry a suite of advanced sensors, be in an orbit similar to the currently operational polar

orbiting satellites previously discussed, and have direct readout transmission services. Of special note to the direct readout user community is that the current APT service will be replaced by LRPT (Low Rate Picture Transmission) service beginning with METOP-1, and on U.S. satellites launched much later in the decade. The LRPT service will be digital rather than analog, requiring modification to installed receiving stations.

THE UNITED STATES GOES GEOSTATIONARY SATELLITES

As discussed in the beginning of this chapter, satellites in geostationary orbits above the equator maintain their apparent positions relative to points on the Earth's surface. This is because the period of the satellite orbit is equal to the Earth's rotation period. As the satellites are orbiting around the Earth, the Earth rotates below them at the same angular rate. Thus, the satellite remains over the same point on the equator, and from the ground, appears to be "fixed" in the same position in the sky. This type of orbit is particularly advantageous for meteorological/environmental remote sensing because the same areas of the Earth can be viewed continuously. Also, because of their high altitude, large areas of the Earth can be seen by the same satellite. A two-satellite system can cover almost all of North America and South America from the Pacific to the Atlantic. When operational, these satellites are usually referred to as GOES-East and GOES-West. GOES-East is positioned at 75 degrees West longitude, with GOES-West positioned at 135 degrees West longitude.

The first prototype satellite of this type was developed with NASA funding and launched on May 17, 1974. The designation, SMS- I for Synchronous Meteorological Satellite, was used by NASA. SMS-2 was launched on February 6, 1975. The first NOAA funded geostationary satellite, GOES- 1, was launched in October of 1975. An updated version of the spacecraft was launched in September 1990, and consisted of the GOES D-G (GOES 4-7) satellites. A new series of GOES satellites, referred to as GOES I-M, began with the launch of GOES-8 in April 1994 and is now on operational status, with GOES-East (GOES-8) and GOES-West (GOES-9).

The GOES series satellites were designed to provide nearly continuous and repetitive observations needed to predict, observe, and track severe weather. Instrumentation on the spacecraft observes the Earth's cloud cover, snow and ice cover, surface and cloud top temperatures, vertical distributions of atmospheric temperatures and humidity, and other environmental data. GOES also measures solar X-rays, collects and relays data from environmental remote platforms and buoys, and can broadcast instrument data to ground stations within the satellite communications "foot print." The general mission of the GOES satellites include:

- Earth imaging and data collection
- Space environment monitoring Data collection
- High Resolution (VAS and GVAR) direct readout transmissions
- Low Resolution WEFAX direct readout transmissions
- Search and Rescue

While the mission is essentially the same, the older GOES D-H series platform and the

GOES I-M (GOES-8 and GOES-9) spacecraft differ significantly in the spacecraft design and instrumentation packages.

GOES I-M Spacecraft

The GOES I-M is the current generation GOES spacecraft. Built by Space Systems/Loral, it is the first three-axis stabilized geostationary weather satellite. It uses a three-axis stabilized attitude control system, implying that the three axes of the satellite remain stationary relative to their pointing axis. These satellites use internal momentum wheels to provide attitude control.

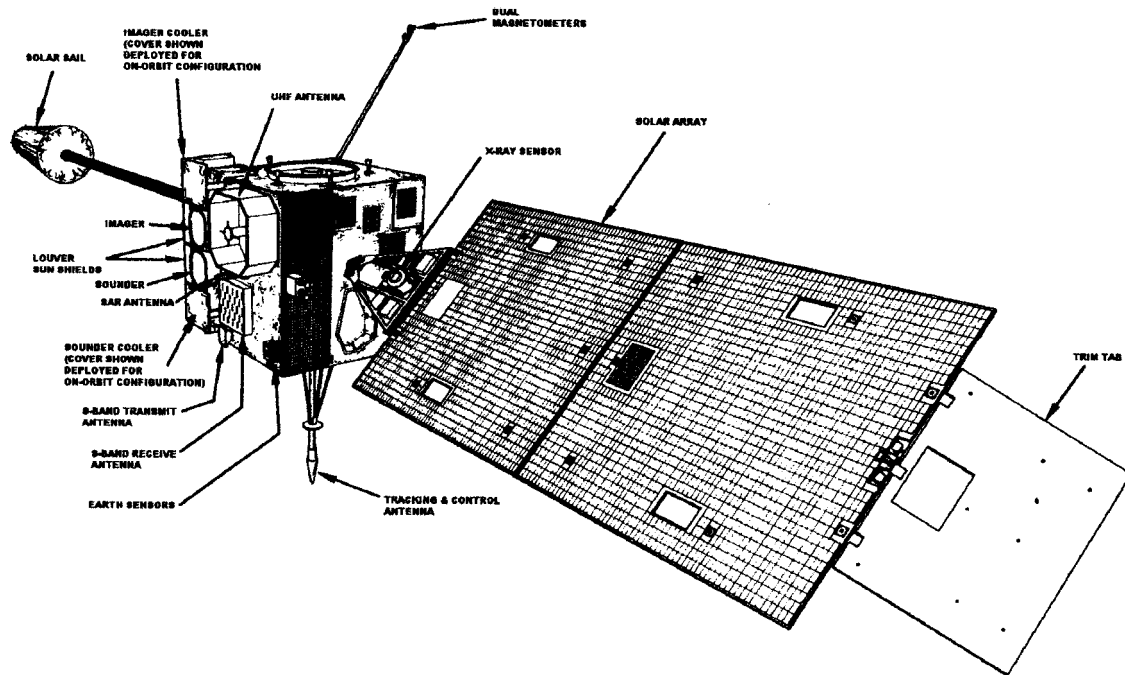


Figure III-8. Diagram of a GOES I-M series satellite with the location of major components. The Imager and Sounder, on the left, would be facing the Earth.

The GOES D-H spacecraft was a spin-stabilized platform, consisting of a vertical cylinder covered with solar panels, containing the instrumentation and antennas. The spacecraft spun at 100 rpm about its vertical axis, which is oriented parallel to the Earth's surface. The gyroscopic effect of the spinning improved the stability of the satellite, making it easier to design a scanning instrument to take stable imagery of the Earth.

A major improvement over the GOES D-H series is that GOES I-M have a capability for independent and simultaneous imaging and sounding from geostationary orbit. This is accomplished by using two, independent instruments: one for radiometric imaging, and the other for radiometric sounding. This provides improved weather pictures and atmospheric sounding.

There is also a capability for rapid, small area scanning for severe storm detection and tracking, as frequently as once per minute.

The complement of instruments in the GOES I-M payload section includes:

- Five-channel Imager (4 IR and 1 visible)
- Nineteen-channel Sounder (19 IR and 1 visible)
- Space Environment Monitor (SEM) consisting of
 - Energetic Particle Sensor
 - High Energy Proton and Alpha Particle Detector
 - X-Ray Sensor
 - Magnetometer
 - Solar X-Ray Imager
- Data Collection System
- WEFAX
- Search and Rescue

The GOES I-M uses a new format called GVAR (Goes VARiable) for data transmission. This format is primarily used to transmit the meteorological data measured by the Imager and Sounder instruments. The WEFAX data format is identical to the GOES D-H satellites. Again, the GVAR and WEFAX images are direct readout products that can be received by any ground station within the footprint of the GOES downlink signal. The GVAR data is a digital downlink at 2.11 Mbps, transmitted at 1685.7 MHz. The WEFAX format is identical to previous GOES D-H analog signal, and transmitted at 1691.0 MHz.

The primary meteorological instruments on the GOES I-M are the 5-channel Imager and 19-channel Sounder. The Imager has a pair of servo motors that precisely move the instrument optics to produce an image. A scan line is produced by moving the optics in an East-to-West direction. At the end of the scan line, another motor slightly changes the optics elevation in a North-to-South direction, and the next scan line is swept in a West-to East direction. This process is repeated to produce the required image. The Imager can produce full Earth disk images every 26 minutes, 24 hours a day, in visible and infrared spectra. This schedule can be changed to produce smaller sectors of the Earth during the development of severe storms at shorter time intervals. The instrument resolution is 1 [km. in](#) the visible range and 4 km. or 8 [km. in](#) the infrared ranges.

Atmospheric sounding data are obtained by having the Sounder repeatedly scanning the same Earth swath. The Sounder operates in a manner similar to the Imager, with two motors controlling the East-West and North-South movement of the instrument optics. The instrument can produce sounding data over a 3000 by 3000 km. every 42 minutes. As with the Imager, the Sounder can be directed to scan smaller sectors, as needed.

The GOES I-M system products a large number of primary or derived data products. These include:

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Basic day/night cloud imagery

Winds derived from cloud motions at several levels and hourly cloud-top heights and amounts

Sea surface temperature data

Albedo and infrared radiation flux to space, important for climate monitoring and climate mode validation
Detection and monitoring of natural and manmade forest fires/biomass burning and smoke plume monitoring
Precipitation estimates
Vertical temperature and moisture profiles

These data products enable users to accurately monitor severe storms, determine winds from cloud motions, and when combined with data from conventional sensors, produce improved short-term weather forecasting and analysis.

The improvements in the spacecraft stabilization, Imager and Sounder provide superior direct readout products as compared to GOES D-H. Improvements in the GOES I-M data products include:

Higher quality imaging acquired more frequently
Improved visible spatial resolution (1 km.) Improved IR spatial resolution (4 km.)
Better water vapor imaging (identify small scale disturbances within large scale features) Improved forest fire detection (20-50 acre)
Improved fog detection
Improved hurricane trajectory forecasts from cloud motion
Improved moisture determination for precipitable water monitoring

The Space Environment Monitor (SEM) collects data involving solar activity that is exhibited as high energy particles, solar X-rays and magnetic flux. Data from the SEM is valuable in providing information concerning high altitude and space radiation, solar activity, and radio wave propagation.

Data Collection System (DCS) equipment on the GOES satellites allow direct relay from remote reading platforms located on the Earth's surface. These platforms contain remote sensors and automatic data transmission equipment that allow information to be sent directly to the satellite from remote sites on the oceans, on land, and in the air where continuous data collection would be difficult or impossible. The environmental parameters that can be monitored are quite varied from these platforms. Data such as river heights, precipitation, earthquakes, ocean currents and temperatures, water pH, wind speed and direction, and barometric pressures are examples of the data sensed by these remote platforms. The data from these platforms are received by radio equipment on the GOES satellites and then relayed to ground stations for decoding and distribution to the operators of the remote platforms. More information is available from the NOAA/NESDIS DCS Coordinator on this system (see Appendices).

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GOES I-M also provides instantaneous relay functions for the SARSAT (Search and Rescue Satellite) system. A dedicated search and rescue transponder on board GOES I-M is designed to detect emergency distress signals originating from Earth-based sources (ships at sea, planes, etc.). These unique identification signals are normally combined with signals received by a low-Earth orbiting satellite system (POES) and relayed to a search and rescue ground terminal. The

combined data are used to perform effective search and rescue operations. Figure III-9 shows a diagram of the GOES I-M satellite and the various sensors and payload equipment.

GOES I-M Direct Broadcast Services

There are two types of direct readout services provided by GOES I-M satellites, GVAR and Weather Facsimile (WEFAX). Both of these data products can be received by any ground station within the "footprint" of the satellite signal. The GVAR data is the high resolution (1 km. visible, 4 km. infrared, 8 km. water vapor) Imager data and the Sounder data, and is transmitted at the Sband frequency of 1685.7 MHz. The data is transmitted to the ground station at 2.11 Mbps. This GVAR data is not generally received by the standard "amateur" ground station.

The Weather Facsimile (WEFAX) images transmitted by the GOES satellites are of most interest to operators of low cost ground stations. WEFAX transmissions contain images and charts transmitted via a 2400 Hz tone format similar to the polar orbiting APT data. This is important because an image display system that can reproduce APT signals can be adapted to display WEFAX images from the GOES satellites. The WEFAX service has been a feature of the GOES system since 1975. The service uses the spacecraft as a transponder to transmit low-resolution imagery sectors as well as conventional weather maps to users with lowcost reception equipment. There are, as noted earlier, some significant differences between APT and WEFAX:

WEFAX images are formatted in a 240line/minute transmission rate contrasted to the 120 line/minute transmissions from the polar orbiting satellites. WEFAX direct readout is transmitted as an analog signal on 1691.0 MHz contrasted with the 137 to 138 MHz band used for APT.

WEFAX transmissions contain images of large sectors of the Earth that are transmitted on a predetermined 24 hour schedule. The primary mode of transmission involves breaking up the Earth disc into four quadrants: Northwest (NW), Northeast (NE), Southwest (SW), and Southeast (SE). Tropical East (TE) and Tropical West (TW), both centered over the equator, are also available.

WEFAX transmissions are sent in both visible, infrared, and water vapor modes. Grids outlining the political and geographic boundaries, and longitude and latitude references (added by the NOAA command and control ground stations) assist in navigation of the imagery. WEFAX is also used to transmit computer-generated Mercator or polar orbiter mosaics from the visible and infrared POES imagery. Weather charts, GOES WEFAX transmission schedules, and TBUS prediction messages are also transmitted on a scheduled basis. A limited amount the imagery from the European METEOSAT satellite is added to the GOES-East transmission, and imagery from the Japanese GMS satellite is added to the GOES-West transmission. This extends the coverage

beyond that of either of the two U.S. geostationary satellites. Up to 13 maps or images can be transmitted through the GOES I-M satellites every half hour, and it is the goal of the ground data

handling system to transmit GOES I-M WEFAX imagery within a half-hour of its original receipt at the command and data acquisition station.

Requirements for reception of WEFAX direct readout from GOES I-M will be discussed in the next chapter on "Basic Ground Station Equipment."

GOES-EAST WEFAX (GOES-8) SCHEDULE - 05/21/96 (Example)

XMIT PRODUCT Schedule Time

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0042      MET-5 00302 D3 IR
0046      GOES-8 23452 NH IR
0050      W500 48 HR 250MB HT/TEMP/WND
0100      W501 72 HR SLP/1000-500TK
0105      W502 72 HR 500MB HT/TEM/WND
0110      GOES-8 23452 NE IR
114 GOES-8 23452 SE IR
115 0118 GOES-8 23452 NW IR

0122 GOES-8 23452 SW IR

0126 GOES-8 23452 4KM US IR

0130 GOES-8 23452 16KM FD IR

0134 GOES-8 23452 NH WV

0138 GOES-8 23452 NE WV
    142 GOES-8 23452 SE WV
0146 GOES-8 23452 NW WV
        0150 GOES-8 23452 SW WV
        0154 GOES-8 00452 NH IR
        0158 GOES-8 23452 16KM FD WV
        0202 GOES-9 0000Z NH IR
        0206 GOES-9 0000Z FD IR
        210 NOAA-14 POLAR VIS NH 010E-080W W026

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Table III-3. Sample Portion of GOES EAST WEFAX Transmission Schedule

Table III-3 shows a sample portion of a WEFAX transmission schedule of GOES East. Note that this segment of the transmission schedules included GOES-EAST data, METEOSAT-5 re-transmissions, various weather charts, re-transmissions from GOES-WEST, and NOAA-14 polar orbiter mosaics. Because this schedule is changed from time to time, information on the most current schedule should be obtained from sources listed in the Appendices.

GEOSTATIONARY WEATHER SATELLITES OF OTHER COUNTRIES

In addition to the United States, a European consortium has launched a series of geostationary satellites, as has Japan. Russia has an operating satellite; China has plans to launch such a satellite, and India operates a geostationary satellite (INSAT) for domestic use.

The European Satellites

The European Space Agency also operates a series of geostationary weather satellites called METEOSAT (METEOrological SATellite). This series of satellites has both a low resolution direct readout similar to GOES WEFAX (called Secondary User Data Station or SDUS), and a high resolution direct readout image called High Resolution (HR), designed for the Primary User Data Station (PDUS). During the period when GOES-6 and GOES-7 primary imaging systems were failing, METEOSAT-3 was moved to a position of 75 degrees west longitude, to provide better coverage for North America and the Atlantic during hurricane season. Direct readout stations in the United States were thus able to receive the WEFAX transmissions at 1691.0 MHz (same format as the GOES WEFAX), and for stations appropriately equipped, the high resolution digital PDUS data at 1694.5 MHz.

With the launch and operational status of GOES-8 and GOES-9, METEOSAT-3 has been moved off position at 75 degrees West longitude and its direct readout products no longer received in the United States. The current satellite (in July 1997) is METEOSAT-6, launched in 1993. METEOSAT-7 is scheduled for launch in 1997, and a new MSG-series of satellites will be launched beginning 2000-2001.

The Russian Satellite

The former Soviet Union has been attempting for decades to develop an effective geostationary satellite program. Due in part to the very high latitude of their launch sites, it has been difficult for Russia to design, build, and launch a dependable geostationary weather satellite system. In 1994, Russia has launched a satellite Geostationary Operational Meteorological Satellite (GOMS) called ELEKTRO-1 that is in a geostationary orbit at 76 degrees East. During 1996 and 1997 the GOMS has been operating erratically, and there have been problems with the imaging sensors. Data has been of variable quality. An ELEKTRO-2 satellite is scheduled for launch during 1998.

The Japanese Satellites

Japan has launched a series of Geostationary Meteorological Satellites (GMS); the current satellite is GMS-5 launched in 1994, and in orbit at 140 degrees East. The design is very similar to

the United States GOES satellites through GOES-7. That is, it is a spin stabilized satellite with a VISSR 4 channel sensor (1 visible, 3 infrared channels). It transmits both a primary data stream, and a WEFAX transmission on 1691.0 MHz. A new, advanced series of geostationary satellites will begin with the launch of MTSAT-1 in 1999.

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The Chinese Satellite

The Chinese geostationary satellite program has begun with the launch of the FY-2B satellite in June 1997. It was placed in orbit at the Equator and 105 degrees East. It is a spin stabilized satellite with a VISSR-type instrument. There will be a WEFAX transmission for direct readout users. When this publication went to press, early indications were the FY-2B satellite was performing satisfactorily.

POES Versus GOES Satellites: Why Two Systems?

One may question why two separate weather satellite systems are required to monitor the Earth's ever changing weather? The answer is related to the types of coverage and timeliness of the data required by meteorologists.

To review the basics, the POES satellites orbit the Earth once every 102 minutes at approximately 450 miles altitude. The orbit is North-South in a near-polar orbit, passing close to both poles of the Earth. The Earth rotates about 25.6 degrees for each orbit of the satellite (15 degrees per hour). A constellation of two POES satellites, with orbital phasing adjusted to provide data for every region of the Earth every 12 hours in the visible spectrum and every 6 hours in the infrared spectrum.

The GOES satellites appear to be stationary above a specific point on the Earth, and the images and soundings are limited to a fixed area that is in view of the footprint. For example, the Continental United States (CONUS) can be imaged every 12 minutes and sounder data acquired every 40 minutes. Five satellites equally spaced around the world could provide worldwide meteorological coverage.

The POES satellites cover nearly the entire Earth's surface, but infrequently, while GOES covers a more limited area of the Earth frequently. POES supports the large-scale, long-range weather forecasts while GOES supports smaller scale, short-range forecasts. GOES tracks severe localized weather such as thunderstorms and hurricanes on a frequent basis. Table 111-4 shows a comparison between the POES and GOES satellites

	<u>Advanced-TIROS Polar</u> <u>orbiter (POES)</u>	<u>Geostationary Operational</u> <u>Environmental</u> atellite <u>(GOES)</u>
<u>Basic Mission and</u> <u>Operations</u>	Two-satellite constellation in polar orbit. N to S (AM satellite), S to N (PM satellite)	Two geostationary satellites cover area from North to South America, from mid Atlantic to mid-Pacific Oceans
<u>Orbital Altitude</u>	AM orbit: 833 km. (518 miles) PM orbit: 870 km. (541 miles)	35,790 km. (22,240 miles) located over the Equator

<u>Orbital Location</u>	Sun-synchronous orbit inclined 98 degrees to Equator	GOES-E 75 degrees West, GOES-W 135 degrees West, in the Clarke belt over the Equator
<u>Orbital Velocity</u>	17,000 mph (102 minute orbital period, 14 orbits per day)	6,800 mph (24 hour orbital period, one orbit per day)
<u>Imaging Coverage Area</u>	1,700 mile wide swath on each pass	Hemispheric coverage
<u>Primary Instruments</u>	AVHRR, TOVS, SBUV, ERBE, DCS, SEM, Search and Rescue	Imager, Sounder, DCS, SEM, Search and Rescue
<u>Primary Direct Readout Products</u>	Analog Automatic Picture Transmission (APT), digital High Resolution Picture transmission (HRPT)	Analog WEFAX transmission digital GVAR transmission
<u>Direct Readout Frequencies</u>	APT: 137.5 or 137.62 MHz HRPT: 1698 or 1707 MHz	WEFAX: 1691 MHz GVAR: 1685.7 MHz

Table III-4 A Comparison Between the POES and GOES Satellites

IV. BASIC GROUND STATION SYSTEM

Technological advances in microelectronics and computer software applications over the past decade have made it rather simple to assemble and use a basic direct readout ground station. Previous editions of the Guide have discussed using government surplus radio receivers to receive the satellite signals, and old photographic facsimile drum recorders to reproduce the APT or WEFAX imagery. Use of such equipment is fairly outdated for today's direct readout environment. One can purchase off-the-shelf, state of the art commercial products for the same cost as the older government surplus and electro-mechanical drum recorders.

When planning the installation of a direct readout system, several issues must be considered:

Do you purchase a complete "turn-key" system from a commercial source or,

Do you purchase individual components (antenna, receiver, demodulator, software, etc.) and assemble a system yourself?

Is the direct readout station primarily for low resolution imagery (APT and WEFAX), or do you require high resolution capabilities (HRPT and GVAR)?

As always, what are the financial considerations and limitations for assembling a complete direct readout system.

Most newcomers to weather-satellite imagery start by assembling a polar orbiter receiving station for the Automatic Picture Transmission imagery. Later on, the additional equipment required for GOES WEFAX reception may be added to this basic ground station. Starting with a basic APT system allows the user to become familiar with satellite image

reception techniques, receiving satellite radio telemetry from a fast-moving platform in space, learning the techniques of predicting satellite orbits and acquisition of signal timing, and analyzing weather patterns and temperature variations in the visible and infrared direct readout imagery. As one gains practical experience with satellite image reception, and as the application requirements change, one may expand the direct readout station to include WEFAX, or migrate to the high resolution HRPT and GVAR commercial systems.

A basic direct readout station typically contains the following components:

Antenna Preamplifier Radio receiver Demodulator card to "decode" the satellite signal

Display system to view the satellite imagery (typically a personal computer)

A storage system (computer disk, tape) to store and archive the satellite imagery
Computer software application to manipulate the imagery (image enhancement)
A method to predict when the satellite will be in view of the ground station

Each of these components will be described in further detail in the following chapters.

The more advanced direct readout systems (HRPT, GVAR) utilize the same basic components, although the receiver design and demodulation system differ due to the nature of the radio frequencies required to transmit and demodulate the high speed digital imagery.

A generalized diagram of the components of a direct readout ground station to receive GOES WEFAX and polar orbiting APT is shown in Figure IV-1. These components are typical of many satellite ground stations currently in operation for the U.S. POES and GOES satellites, as well as the Russian METEOR, OKEAN, Chinese Feng Yun, and METEOSAT satellites.

FEEDHORN
(the quadrifilar helix antenna shown is an example of an omnidirectional antenna)
1691 MHz to 137-138 MHz ANTENNA DOWNCONVERTER

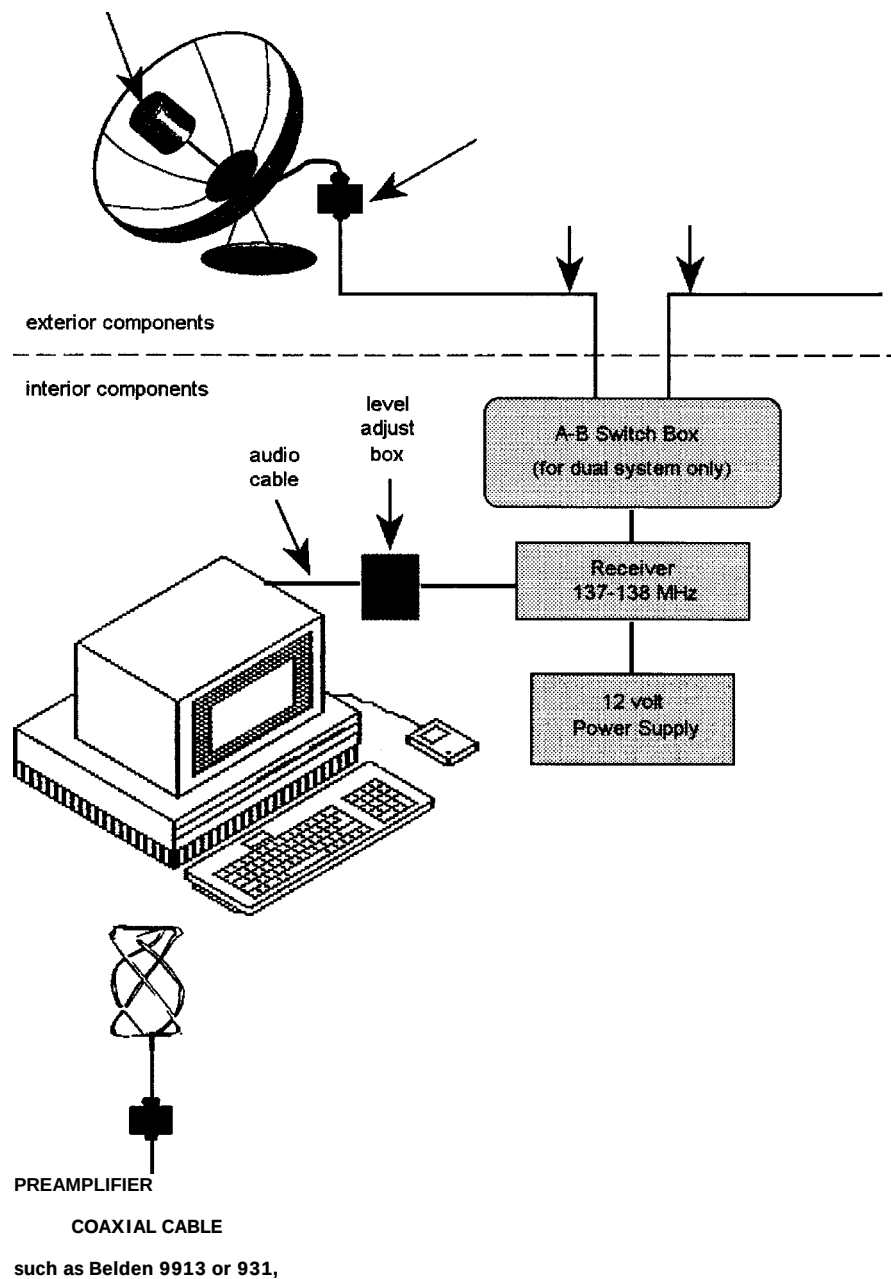


Figure IV-1. Typical components found in a combination APTIWEFAX receiving station

Several different types of antennas may be used for polar orbiting reception of APT imagery. One is directional and requires tracking of the moving satellite and the second type, shown in Figure IV-2, is omnidirectional and less expensive but will give a slightly reduced reception range. Both of these are discussed in Section V of this publication.

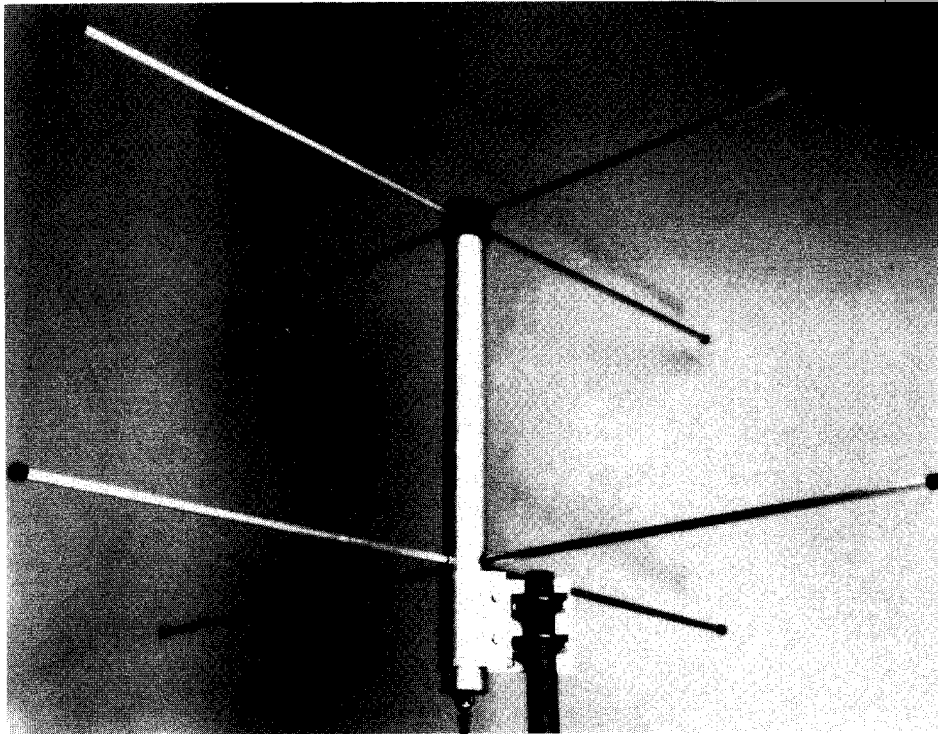


Figure IV-2. Omnidirectional "turnstile" type antenna for APT reception which need not be aimed towards the satellite

At the antenna, the signal is processed by a small preamplifier which serves to reduce unwanted noise and then is passed to the radio through a transmission line. The radio receiver used in most ground stations is a crystal controlled FM receiver with good sensitivity capable of detecting radio frequencies between 137 and 138 MHz. Since each satellite operates at slightly different frequencies, a specific crystal is needed for each satellite that is to be accessed. Some of the more modem radios coming into wide use now have synthesized frequency capabilities and do not require a crystal for each satellite.

The radio receives the FM signal and detects the 2400 Hz amplitude modulated subcarrier which is the satellite image. At this point, if this 2400 Hz tone is inserted into an appropriate display reproduction system the satellite image can be viewed. Some stations also have a stereo tape recorder so that the transmission can be recorded and played back later to make other copies of the image or to be archived for later reference.

A number of display systems are discussed in this publication. The majority are based on personal computers that use specialized demodulator cards and software programs to ingest the

audio signal from the satellite, convert it to a digital signal, display the image on the screen, and store the image to disk. Other software features may be used to digitally enhance the pictures, add geographic gridding or analyze the temperature variations in the infrared imagery.

In order to receive the WEFAX transmissions from the geostationary satellites, additional components are necessary. WEFAX is transmitted on a microwave frequency of 1691.0 MHz, and therefore, a different antenna is required. Most stations use a parabolic or "dish" antenna which receives and reflects the signal into a "feed horn" located at the focal point of the parabolic reflector. Located in this feed horn is a small whip antenna which detects the signal and passes it from the antenna. In order to use the same radio receiver, a down converter is used to convert the 1691.0 MHz signal to 137.5 MHz. Since signal loss at 1691.0 is fairly great in transmission lines, this down converter is usually located near the antenna. From this point the down-converted signal can be carried through conventional shielded cable to the location of the radio. Since the signal is now at a frequency of 137.5 MHz and WEFAX also carries a 2400 Hz subcarrier, the radio will operate as it did to receive the APT transmissions from the polar orbiting satellites. This tone can then be fed to a display system and reproduced in a manner similar to the APT signals. The major difference here is that the display system should be able to reproduce images transmitted at 240 lines per minute.

Reception of HRPT or GVAR imagery requires major upgrades to the above systems. Typically, only the personal computer, display system, and antenna tracking system may be used from the original APT or WEFAX installation. Specifications for commercial HRPT and GVAR stations will be described in the chapter entitled "Advanced Direct Readout Systems."

Figures IV-3 to IV-6 are photographs of typical images received via direct readout of APT and WEFAX using the ground station described above.

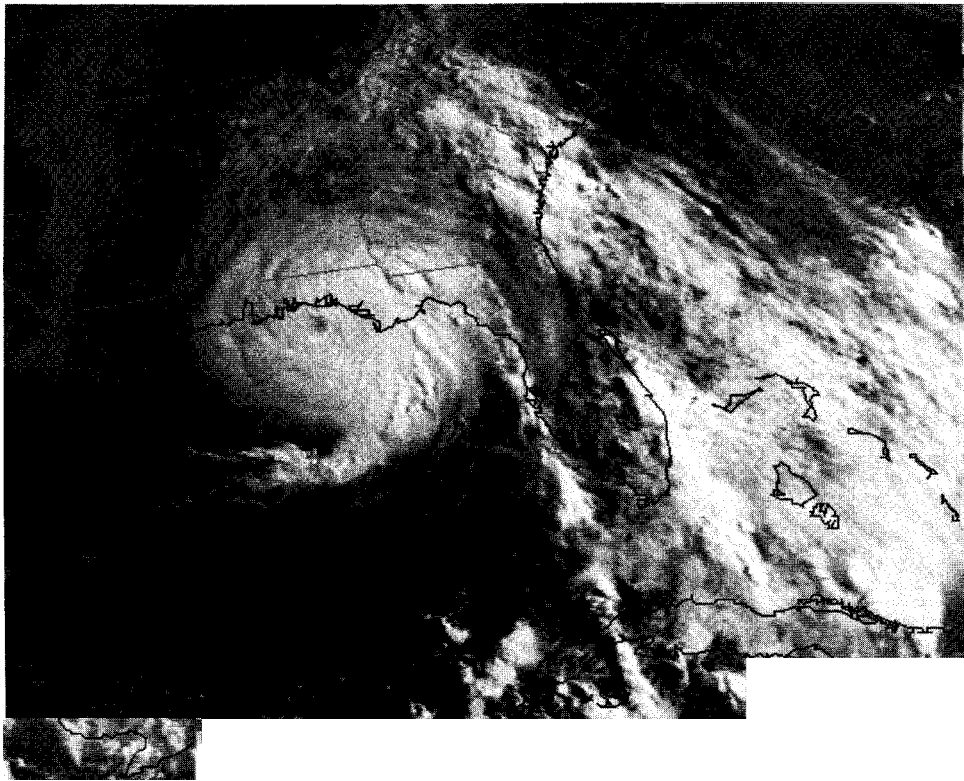


Figure IV-3. APT channel 1 visible image with geographical gridding applied by receiving station software.

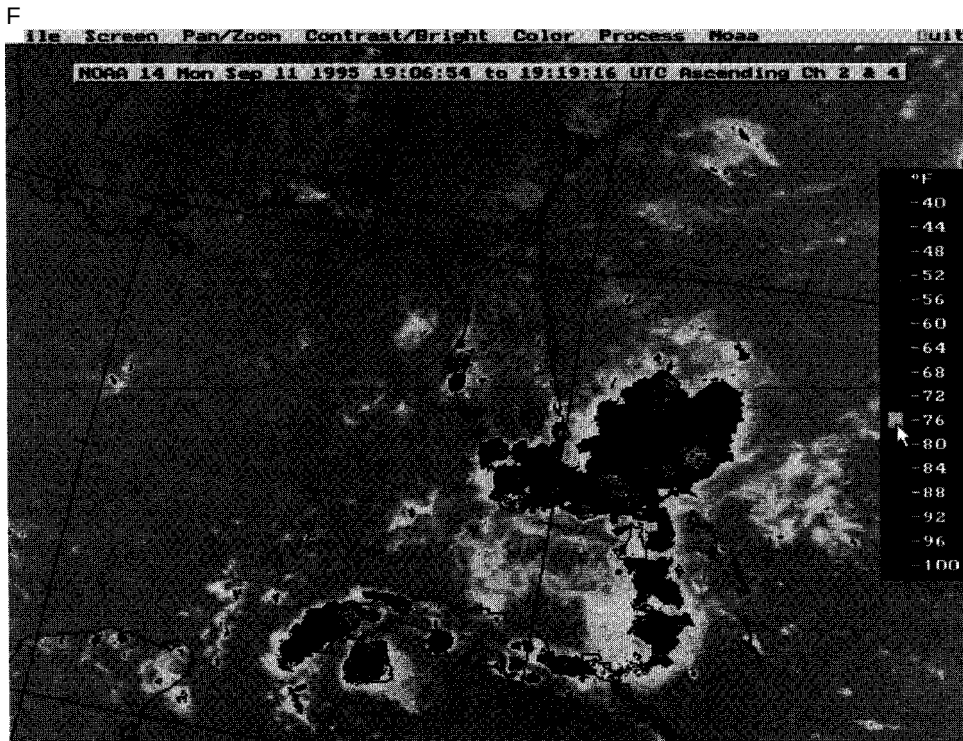


Figure IV-4. APT infrared channel image with geographical gridding and cloud-top temperature thresholds applied by receiving station software.

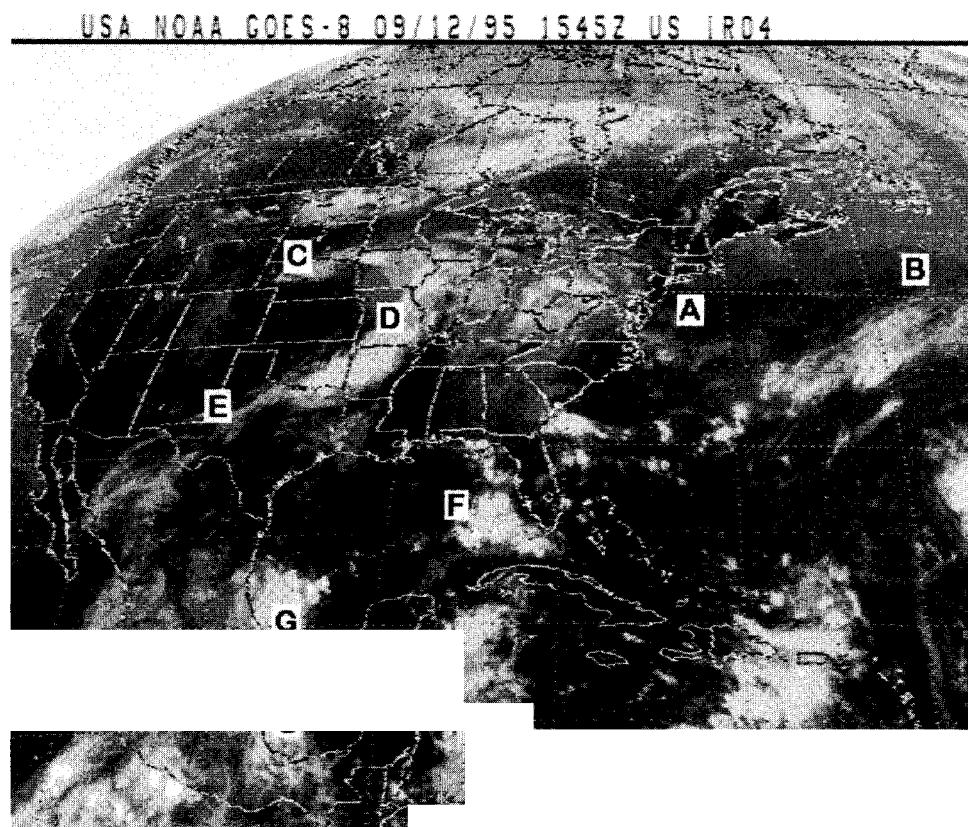


Figure IV-5. GOES-East infrared WEFAX image showing Gulf Stream boundary (A-B), active frontal system (C-D-E), and shower and thunderstorms off Florida and Mexico (F, G).

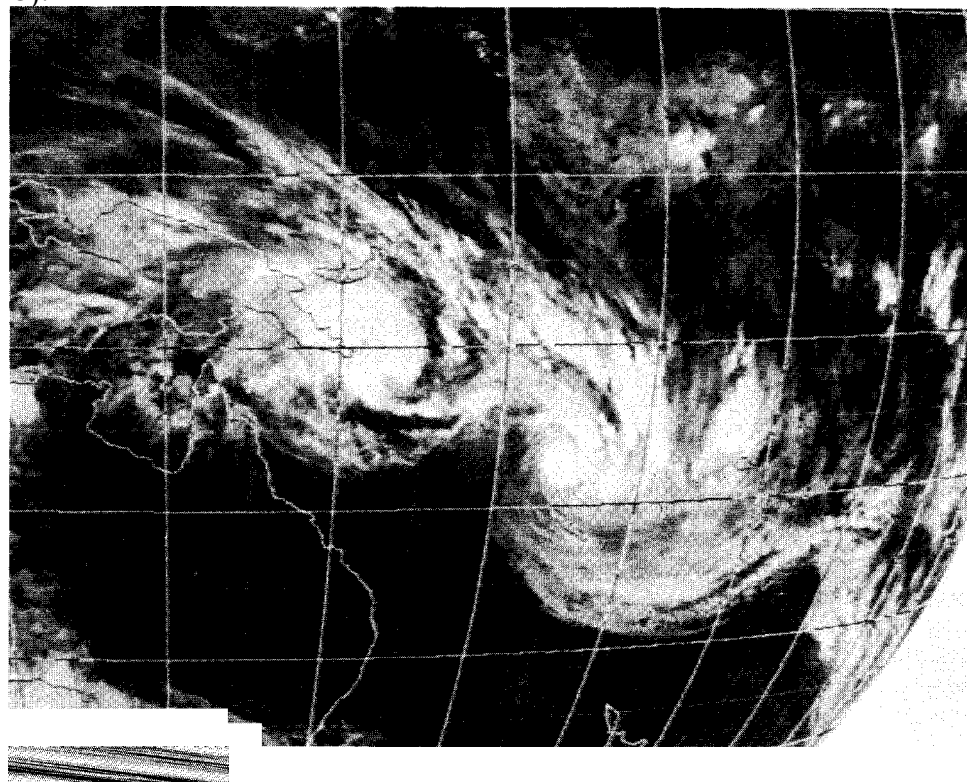


Figure IV-6. Japanese GMS satellite infrared WEFAX image showing two tropical storms northeast of Australia.

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DIRECT READOUT SENSORS AND IMAGE FORMATS

In order to gain an appreciation for the ground station equipment required to receive the polar orbiting and geostationary direct readout imagery, it is helpful to have a basic understanding of the sensors on board these spacecraft, and how the images are created, formatted, and transmitted from the satellites to direct readout ground stations.

Polar Orbiting Environmental Satellite Direct Readout Sensors

The **primary** imaging sensor on the Advanced-TIROS satellites is the Advanced Very High Resolution Radiometer (AVHRR/2) instrument. The AVHRR is the latest in a long series of imaging instruments to be flown on the polar orbiting satellites. The original sensors provided by the early weather satellites were actually television-based systems using automatic (analog) picture transmissions. Since the TV vidicon tubes were very delicate and easily damaged by the rigors of space, they were replaced in later satellites by scanning radiometers.

The scanning radiometer is basically a system of various lenses, motor-driven mirror system, and several solid state sensors sensitive to various wavelengths of the electromagnetic spectrum. The scanning radiometer builds up an image by scanning successive thin lines at right angles to the satellite's orbital track. The system operates continuously, so an image of the Earth below can be received for the full time the satellite is within range of the ground station.

The AVHRR is a five channel scanning radiometer sensitive to visible, infrared, and near infrared portions of the frequency spectrum in the following wavelengths shown in Table IV-1.

The AVHRR instrument scans across the Earth from the space view side of the spacecraft toward the Sun. The direction of the scan allows the image data, when displayed on a computer display or facsimile machine, to maintain the correct geographic orientation for specific orbits. AVHRR utilizes a 45 degree scanning mirror that rotates at 360 rpm. With each rotation of the mirror, data from deep space, an Earth scan, and a warmed black body radiator, which is part of the instrument housing, are taken. The scanning track across the Earth measures both the visible reflected light and infrared wavelengths, building an image in the scanning process. Each infrared channel is effectively recalibrated on every revolution of the scanning mirror. The satellite motion across its orbital track causes the successive scan lines to form a contiguous, twodimensional image. The spectral energy collected by the scanning mirror is passed through five separate optical subassemblies to five separate detectors for the visible, near-infrared, and three thermal infrared channels.

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<u>Channel</u>	<u>Spectral Range (in p.M)</u>	<u>Wavelength</u>	<u>Primary Uses</u>
----------------	--------------------------------	-------------------	---------------------

1	0.58-0.68	Visible	Daytime cloud/surface delineation, snow & ice melting
2	0.725-1.10	Near-infrared	Surface water delineation, sea surface temperature, vegetative indexing
3	3.55-3.93	Thermal infrared	Forest fire monitoring, nighttime cloud mapping, sea surface temperature (nighttime)
4	10.30-11.30	Thermal infrared	Sea surface temperature, day and night cloud mapping, soil moisture
5	11.50-12.50	Thermal infrared	Sea surface temperature, day and night cloud mapping

Table IV-1. AVHRR/2 Instrument sensing characteristics

The Channel 1 detectors (0.58-0.68 μm) are sensitive to visible light, and thus dependent entirely on sunlight reflected off the Earth. Illumination levels need to be quite high to obtain usable visible light images. Land/sea contrast is generally poor, particularly at higher latitudes. Channel 2 (0.73 - 1.1 μm) is reflected infrared energy. This channel is usually assumed to be the "visible" channel on APT transmissions. Land/sea boundaries are very clear and cloud detail is also very good. Channel 2 is the most used daytime channel for APT images. Channel 4 (10.3-11.3 μm) is the long wave infrared channel and is effective both day and night. It is the channel offering good land/sea and cloud contrast during the night and is the channel used for nighttime APT imagery. Channel 5 (11.5-12.5 μm) has very similar characteristics to Channel 4. Channel 3 (3.5-3.9 μm) can image the Earth by both reflected infrared and emitted infrared energy.

When energy falls on the AVHRR detectors, it generates a proportional electric current which is amplified and converted to digital information via an analog-to-digital converter. This digital data is then processed to produce separate data streams that are transmitted by the satellite to the ground stations. These data transmissions are:

1. High Resolution Picture Transmission (HRPT) - Real time 1.1 km. resolution images containing all five spectral channels and telemetry data transmitted as high speed digital data.

2. Global Area Coverage (GAC) - Tape recorded 4 km. digital images that are produced over all regions of the Earth and then are transmitted, on command, to ground stations during the satellite pass.

3. Automatic Picture Transmission (APT) - Continuous real time analog transmissions of 2 channels of processed, reduced resolution AVHRR data.

This digital information is what comprises the actual weather satellite imagery. The total image is composed of 2048 picture elements (pixels) per line by however many lines can be received by a fixed Earth ground station that is tracking the satellite as it moves across the horizon. Each pixel transmitted has a resolution of 1.08 [km. at](#) the satellite nadir point (point on Earth immediately below the satellite sensor). However, as the image moves away from the downward nadir point, the pixels become progressively elongated or distorted, and resolution decreases to approximately 5 km.

High Resolution Picture Transmission Data

The HRPT data format is digital, and is transmitted by the POES satellites at six lines per second (360 lines per minute). Each HRPT scan line is formatted as digital "words," with 11,090 words of information (each of these words is 10 binary digits (bits) long, providing 1024 levels of gray scale). Not all of the HRPT digital data is imagery. Data from the TIROS Operational Vertical Sounder (TOVS), the Space Environment Monitor, the Data Collection System, and the spacecraft telemetry are also transmitted.

Since the HRPT imagery is transmitted as a digital signal (665 kilobits per second, split phased encoded, phase modulated), at radio frequencies of 1698 MHz, 1707 MHz, or (standby) 1702.5 MHz, fairly sophisticated ground receiving equipment is required to receive the radio signal, demodulate the signal, and display on a personal computer. Until recently, an HRPT receiving ground station was not economically feasible for the "casual" user of POES direct readout imagery. The requirements for an HRPT ground station will be covered in the chapter on Advanced Direct Readout Systems.

Automatic Picture Transmission Data Format

The analog APT system was designed to produce real time video that can be received and the images reproduced by low cost satellite ground stations. This data stream is produced by amplitude modulating a 2400 Hz subcarrier with the 8 most significant bits of the 10 bit digital AVHRR data. This results in an analog signal with the amplitude varying as a function of the original AVHRR digital image and data. Two of the five possible AVHRR spectral channels are multiplexed so that channel A APT data is obtained from one spectral channel of the first AVHRR scan line and channel B from another spectral channel contained in the second AVHRR scan line. The third AVHRR scan line is omitted from the APT before the process is repeated. The two spectral channels are determined by ground command and are not selectable by the user. This processing results in the APT containing 1/3 of the data from the AVHRR 360 scan

lines/minute. The resolution of the APT is, therefore, proportionally reduced and is received at the ground station at a rate of 120 lines per minute of video. During the APT formatting, appropriate calibration and telemetry data for each of the selected images is inserted into the transmission. This results in an APT video format as shown in Figure IV-7.

Frame

S A SC CA and A A E R S	Channel 128 A Video Lines	1	S P A Y E N C B and B M A R E R S	Minute Marker , (2 White. Channel B Video 8 Lines	1
		2			2
		3			3
		4			4
		5			5
		6			6
		7			
		8			8
		9			9
		10			10
		11			11
		12			12
		13			13
		14			14
		15			15
		16			16

Telemetry Frame A

Telemetry Frame B

Figure IV-7. APT frame format

As can be seen in Fig IV-7, each APT video line is 0.5 seconds in length, containing two equal segments. Each 0.25 second segment contains:

1. A specific sync pulse
2. Space data with 1 minute timing inserts
3. Earth scan imagery from a selected AVHRR channel
4. A telemetry frame segment

Each 500 ms line of image data contains 250 ms of IR data, and 250 ms of visible light data. While the majority of each 250 ms interval consists of Earth scan data, the sync pulse, space data with 1 minute timing inserts, and telemetry frames are also of interest to the direct readout user. The following paragraph describes these elements.

IR Sync Pulse - Each IR scan line begins with a 832 Hz pulse where the subcarrier swings between white and black for seven cycles. Receiving equipment can detect this 832 Hz sync pulse to detect the IR component of the image. This train of pulses appears in the IR image as a series of fine vertical black and white bars. This IR sync pulse and the visible sync pulse make up the distinctive "tick-tock" sound on the received APT audio signal.

IR Pre-Earth Scan - Prior to scanning the Earth, the IR sensor briefly scans empty space. The IR data format represents cold as white in the image, and therefore space data appears as a white strip down the edge of the IR image. Once each minute, the spacecraft clock inserts minute markers into this pre-Earth scan portion of the image. These minute markers appear as thin, black horizontal lines across the white pre-Earth scan. The black markers provide a 60 second time reference in the image.

IR Earth Scan - The majority of the 250 ms IR scan is the scan of the Earth's surface. Warm objects appear black or shades of gray, with cold objects appearing white or lighter shades of gray.

IR Telemetry - At the end of the IR line is a zone dedicated to telemetry information. This data is coded as step-like changes in brightness, resulting in a strip down the right side of the IR image made up of gray scale step "wedges." This information is used for calibrating temperature data in the image.

Visible Sync Pulse - The visible image follows the IR scan data. The visible scan begins with a seven-pulse sync sequence similar to the IR sync pulse, except it is a 1040 Hz rate so that the receiving equipment can discriminate between the IR and visible sync pulses. The visible sync pulses appear as narrower vertical black and white stripes down the left side of the image as contrasted to the IR sync pulses.

Visible Pre-Earth Scan - the scan of deep space in visible light produces a black stripe down the side of the visible image. The 60 second clock data appears as white horizontal lines across the vertical black strip.

Visible Light Earth Scan - the majority of the 250 ms visible light interval is taken up by the Earth scan data. This is a scan using reflected light from the Earth's surface, oceans, and clouds. Clouds appear in varying shades of white, water as black, and land features various shades of gray.

Visible Light Telemetry - the visible scan line ends with a telemetry window similar, but not identical, to the IR telemetry wedges.

During daytime passes, the APT format shows the visible data and IR data. During nighttime passes, the ground control stations may command the satellite's onboard computer to insert data from another IR channel to replace the visible channel, as the visible channel data

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would appear all black during a nighttime pass. The two IR channels would sample slightly different spectral bands, and thus would appear different from each other.

Geostationary Satellite Sensors

The GOES I-M satellites have an independent Imager and Sounder instrument that may operate simultaneously with no degradation of either data product. Raw data output from the

spacecraft is received at a NOAA Command and Data Acquisition (CDA) ground station, where it is demodulated, processed, and output in the GVAR format by the Sensor Processing System at the CDA. After processing the data, the calibrated, earth-located, GVAR formatted data is re-transmitted back up to the GOES satellite, which in turn, retransmits it to the direct readout stations on the ground.

The GOES I-M satellites carry a five-channel (four infrared and one visible) Imager and a 19 channel (18 infrared and one visible) Sounder. This is an improvement over the GOES D-H series in that the Imager has simultaneous imaging from all infrared and visible channels and provides higher infrared resolution (4 km) in the surface and cloud detection channels. The new Sounder has isolation and independence from the Imager and the Sounder has more and narrower spectral channels.

Imager channels 1, 2, 4, and 5 correspond approximately to the Advanced TIROS-N AVHRR channels 1, 3, 4, and 5. GOES Imager channel 3 is centered on 6.75 μm .

GVAR (Goes VARIABLE) Data Format

The majority of the direct readout community utilizes the NOAA POES APT and HRPT imagery, and WEFAX imagery from the GOES satellites. Due to ground station complexity and cost constraints, a smaller portion of the direct readout population is currently receiving the high resolution GVAR image products. However, costs for GVAR readout stations have fallen over the past few years and the increasing number of users of these data now include small commercial enterprises, educational institutions and even a few amateurs.

The GVAR data format has its origins with the earlier GOES VAS Mode AAA format. The AAA format consisted of a fixed length format composed of twelve equal size blocks. The GVAR transmission consists of twelve blocks numbered 0 through 11. Blocks 0 through 10 are transmitted as a continuous set for each Imager scan swath, which is eight lines. Block 10 is followed by a variable number of Block I I's according to what data is available for transmission.

The GVAR data is digital data re-transmitted to the direct readout ground stations at 2.11 Mbps. Resolution is 1 km. for the visible channel, 4 km. for three of the infrared channels, and 8 km. for the water vapor channel.

Geostationary WEFAX Data Format

The GOES WEFAX data is transmitted as an analog signal, similar to APT, at 1691.0 MHz. The WEFAX image, however, is initially formatted by NOAA ground control stations, using high resolution GOES image data, polar orbiter mosaics, weather maps, WEFAX transmission schedules, and re-broadcast through the GOES satellite back to direct readout ground stations. It is thus a delayed direct readout product, or near real time. The WEFAX

transmissions are individual frames or pictures that require 200 seconds to be transmitted. The images are transmitted at 4 lines per second, or 240 lines per minute. Thus, each WEFAX scan line is 250 ms in duration.

The U.S. WEFAX transmission consists of the following:

Start Tone - Each WEFAX image starts with 300 Hz square-wave modulation of the subcarrier for a period of 5 seconds. This start tone is very distinctive and is used by the receiving equipment to indicate a new image frame is about to be transmitted.

Phasing Interval - The GOES phasing signal is 5 seconds long and follows the start tone. The phasing interval is when the subcarrier is at the white level, interrupted by 12 ms pulses where the subcarrier drops to the black level. The black pulses occur four times a second, and act as markers to allow the display system to get in phase with the beginning of the upcoming image line.

Binary Coded Header - The Binary Coded Header (BCH) consists of 50 computer readable characters evenly spaced across 4 lines following the phasing signal. The Header contains information about the satellite, date/time group, sensor channel and sector. This allows a software solution to scheduling reception of certain sectors or images rather than being dependent on the scheduled time of transmission.

Gray Scale - The gray scale is 5 lines or 20 seconds in length following the BCH. The gray scale consists of 16 equal segments ranging from black at the left edge of the picture to white at the right edge. Each segment can be represented by a value between 0 and 255. Thus, the 16 segments, left to right, have values of 0, 17, 34, 51, ... 255.

Image Transmission - Upon completion of the phasing interval, the image transmission begins. It is sent at 4 lines per second, and takes 200 seconds to receive a complete image frame. The image begins with a narrow black vertical bar at the extreme left side of the scan line, a narrow white level framing interval immediately to the right, the image data, and a narrow white border at the right side of the scan line.

Stop Tone - When the image frame is complete, the subcarrier modulates at a frequency of 450 Hz between the white and black levels, for 5 seconds. The stop tone is used to disable the display system at the completion of transmission of the image.

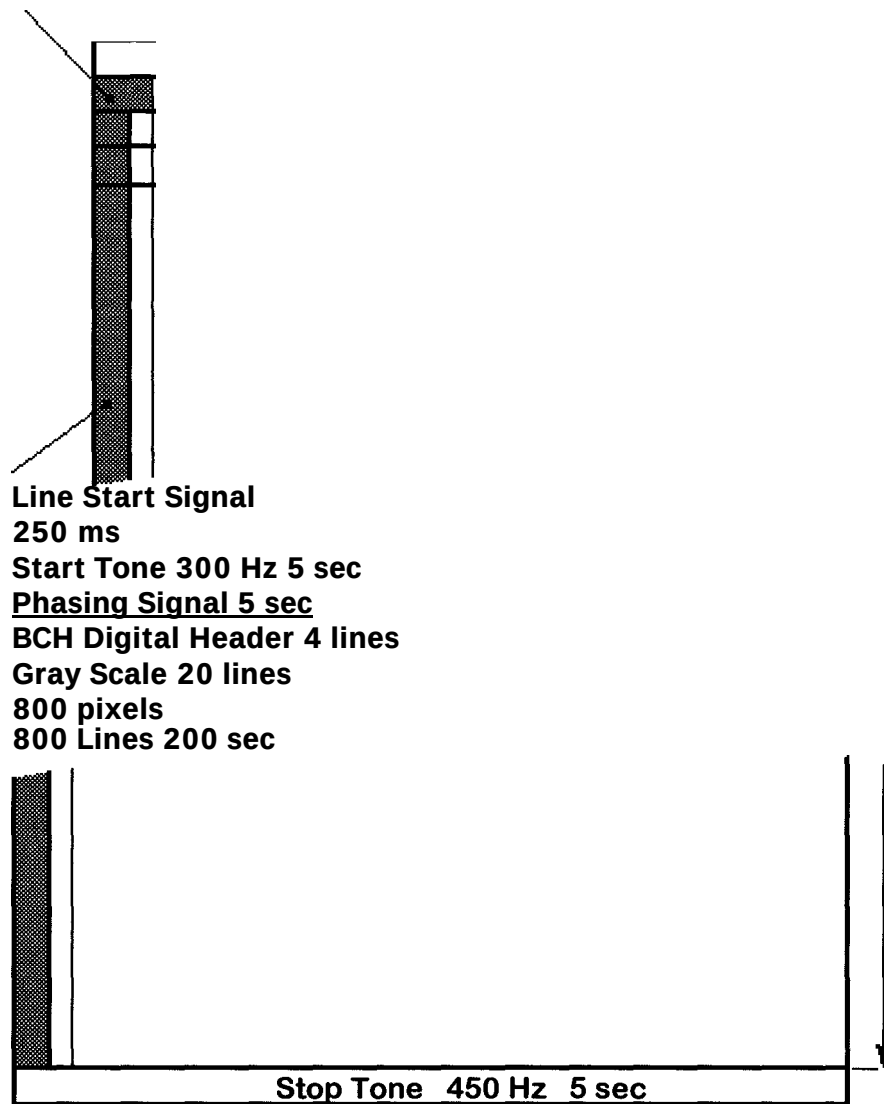


Figure IV-8. WEFAX frame format

The GOES WEFAX imagery consists of visible, infrared, and water vapor images of the Earth. Geopolitical gridding and longitude/latitude registration lines are inserted into both the visible and infrared WEFAX imagery on GOES-8 and GOES-9.

In the chapters to follow, the main components of polar-orbiting and geostationary satellite receiving systems will be examined in detail.

V. ANTENNA SYSTEMS FOR APT AND WEFAX

Antenna systems for weather satellite reception consist of two primary elements, the antenna and the transmission system. Several design factors will determine how well an antenna system will function and thus will impact the overall quality of the weather satellite imagery. The three design considerations of primary importance include:

1. The physical size of the antenna components is determined by the frequency of the transmissions it is intended to receive. In most Very High Frequency (VHF) antenna designs, the driven elements or radiating elements are designed for $\lambda/4$ or $\lambda/2$ wavelengths.
2. The antenna design should fit the type of RF signal polarization it is to receive.
3. The antenna needs to produce sufficient signal gain to produce noise-free reception whenever it is used with an appropriate radio receiver.

Several key definitions are required to fully understand the design and function of antenna systems. These include gain, beamwidth, and polarization:

Gain - The *gain* of an antenna is the measure of how much the antenna increases the level of the signal relative to some reference point. This reference point is usually a simple dipole antenna. Gain is based on a logarithmic scale, and the units of gain measured in decibels (dB). Since this is a logarithmic scale, a gain of 3 dB indicates a doubling of the signal level. The gain of the antenna will assist in overcoming signal losses in the cable transmission system and result in better overall image quality. However, higher gain usually means a decrease in the beamwidth of the antenna. External preamplifier circuitry can be used in conjunction with the antenna to increase the overall gain and signal strength presented to the radio receiver.

Beamwidth - *Beamwidth* is a measure of the width of the antenna pattern. The wider the antenna pattern, the more signals it will receive from different directions. Generally, the wider the beamwidth or pattern, the lower the gain of the antenna. Thus, a trade off exists for gain and beamwidth. A high-gain antenna must be pointed very accurately due to the narrower beamwidth. For polar orbiting weather satellites, this means that some method of tracking or pointing the antenna will be required. This is usually accomplished with a rotator mounted just below the antenna that can turn the antenna both in azimuth and elevation in order to track the movements of the satellite.

Antennas that are "omnidirectional," or receive signals from many directions, generally have very low gain, but have the advantage of not requiring a method of tracking of the satellite. One special type of omnidirectional antenna is called a quadrifilar design, and receives signals well from all directions.

Polarization - *Polarization* is a function of the orientation of the radio waves in space to that of the transmitting and receiving antenna. Ideally, the receiving antenna should be oriented in space to match the orientation of the transmitted signal, thus maximizing the signal strength. The most common types of antenna polarization include linear (horizontal, vertical) and circular

polarization. TV and FM radio stations usually have horizontally polarized transmitting antennas, and thus TV antennas are designed to have the elements mounted horizontally to the

ground. Police radios and cellular phones typically use vertical polarization, and thus the receiving whip antennas are mounted vertically on the automobile. Satellites, particularly polar orbiting platforms, commonly use antennas with circular polarization. This is due to the fact that satellites are in constant motion, and linearly polarized signals would be constantly changing polarization (and hence signal strength) with respect to linearly polarized ground station antennas. Circularly polarized antennas on both the spacecraft and on the ground provide a more stable received signal strength. A linearly polarized ground antenna can be used for the POES satellites, but significant signal loss would occur due to cross-polarization from the transmitting to the receiving antennas. Geostationary satellites do not move in relation to a ground station, so linear polarized antennas may be used at both the spacecraft and ground station.

At the present time the United States POES satellites are transmitting APT on 137.50 MHz and 137.62 MHz, and the Russian METEOR and OKEAN at 137.85 MHz and 137.40 MHz, with about a five watt signal. The RF signal is circularly polarized on the U.S. spacecraft (right-hand circular) and varies between left and right-hand circularity on the Russian satellites.

Considering the frequencies, signal strength, and polarization factors of the transmissions, a number of antenna designs can accomplish adequate reception when used in conjunction with a good preamplifier and a properly designed radio receiver.

VHF Antenna Systems for APT Imagery

Several different antenna designs work well for the Very High Frequency (VHF) range of 137-138 MHz that the NOAA POES, METEOR, OKEAN, and Feng Yun APT transmissions. These include both omnidirectional antennas and also higher-gain beam antennas.

Omnidirectional antennas:

Turnstile Reflector - The turnstile reflector (see Figure IV-2) antenna is one of the simplest and least expensive antennas to use for APT weather satellite imagery. It is omnidirectional, theoretically receiving the satellite signal from all directions, is easy to mount, and does not require the more complex tracking guidance needed by high-gain directional antennas. The disadvantage of these antennas is that they offer little, if any signal gain and this will result in a reduced area of coverage compared to the higher signal gain offered by directional antennas. Due to the design and placement of the antenna elements in a turnstile, the satellite signal is often received better in one direction than others. This can create some loss of signal strength and a "fading" of the received APT transmission. Fading often results in noise bursts or "sparklies" in the APT video image.

Quadrifilar Helix Antennas - A quadrifilar helix antenna is a special type of omnidirectional antenna that provides a much better "radiation pattern" compared to turnstilereflectors, and does not suffer from the loss of signal strength exhibited in simple turnstile antennas. The quadrifilar helix usually consists of four Y2-turn helices equally spaced around the circumference of a common cylinder. The radiation pattern is omnidirectional in the plane perpendicular to its main axis. Radiation of the signal is nearly circularly polarized over the entire hemisphere irradiated. This makes it almost ideal for receiving signals from polar orbiting weather satellites. Well designed quadrifilar helix antennas often exhibit inherent gain

from 3 dB to 5 dB. A low physical profile combined with high performance makes the quadrifilar antenna an excellent antenna for APT reception in the home. Its small diameter also

allows it to be enclosed in a waterproof housing or made from corrosion resistant materials, making it suitable for marine use.

Figure V-1 is a commercial quadrifilar helix antenna designed for 137 MHz APT reception, and has a built-in preamplifier providing more than 20 dB of signal gain to the satellite receiver.

Pricing differences and performance at low reception elevations are the factors which separate the turnstile and quadrifilar antennas. The quadrifilar antenna will provide virtually noise free reception once the satellite reaches an elevation of 5 to 10 degrees above the horizon. The turnstile will provide slightly less performance at lower elevations levels, but is usually much less expensive than the quadrifilar design.

Directional Antennas:

Directional antennas, such as beams and crossed-yagi designs, offer much higher gain and signal to noise ratios compared to simple omnidirectional antennas. Such directional antennas have very sharp radiation patterns, and require accurate tracking of the satellite to take advantage of the gain provided by the antenna system.

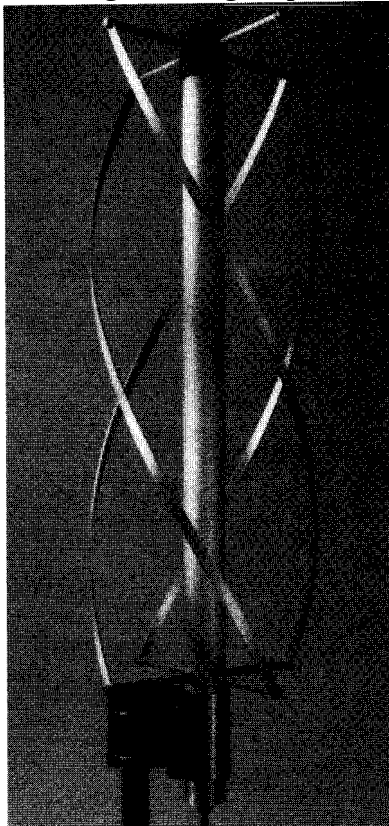


Figure V-1.

The crossed yagi directional antenna has been the popular choice of many "amateur constructed" APT stations. This design functions well for APT reception, is relatively inexpensive, and can be purchased commercially or constructed without much difficulty. All materials needed should be easily obtained locally. The crossed yagi antenna is one of the few components of the modern APT ground station that can actually be built from scratch,

5-3

by the user! Construction details of such an antenna, along with a less effective but very simple omnidirectional antenna, are given below.

The crossed yagi is a directional, beam-type antenna consisting of a number of elements similar to a multi-element TV antenna. The major exception is that the elements are arranged at right angles to each other. This crossed element design eliminates fading of the circular polarized RF signal transmitted by the satellites. Because it is a directional beam design and in order to get maximum signal gain, the antenna must be pointed toward the satellite. This presents an additional problem.

Polar orbiting satellites are NOT stationary. They travel in paths that are generally either north to south (descending nodes) or south to north (ascending nodes). Following or tracking of the satellite by the antenna is therefore necessary. In the design given here, such tracking is accomplished by using two TV-type direction motors. One controls the elevation (angle above the horizon) of the antenna and the other controls the azimuth (compass direction) so that the satellite can be tracked at any elevation angle and direction as it passes within range of the receiving station. The beam width of this antenna is about ± 20 degrees which gives it sufficient width so that pinpoint accuracy is not necessary. Figure V-2 is a picture of a Crossed Yagi Directional Antenna for APT Reception.

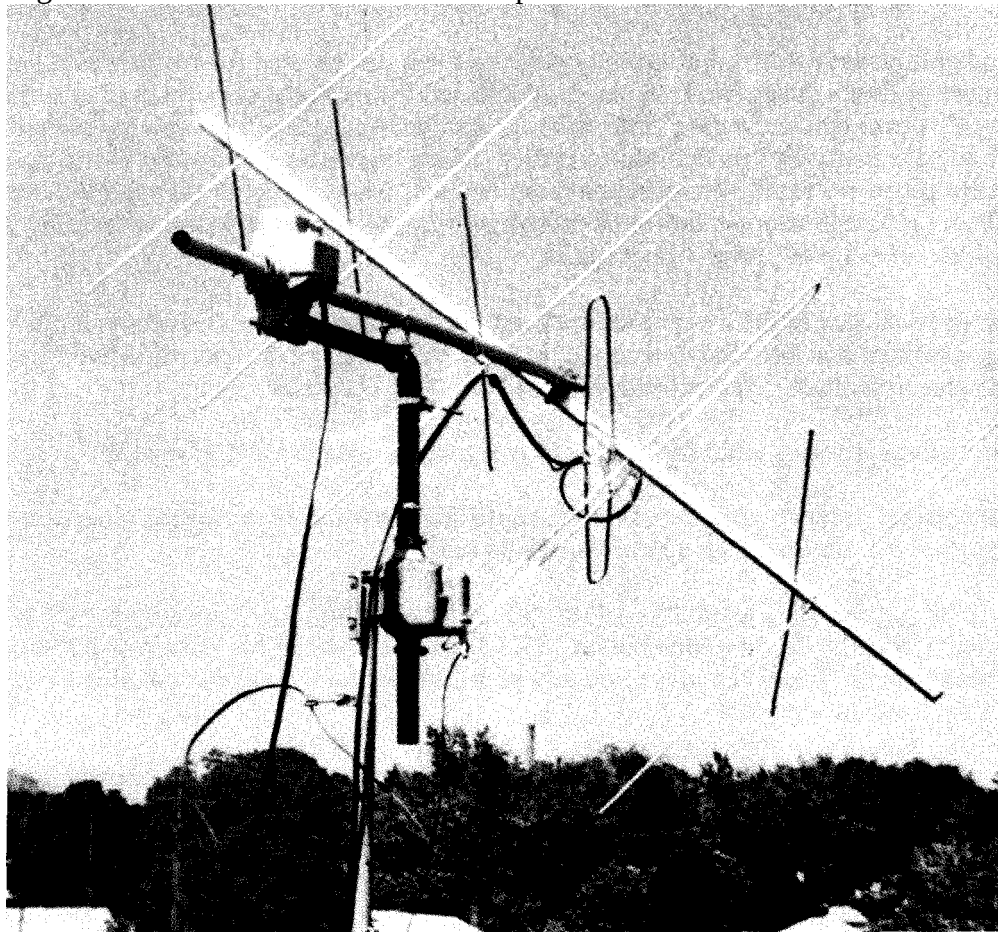
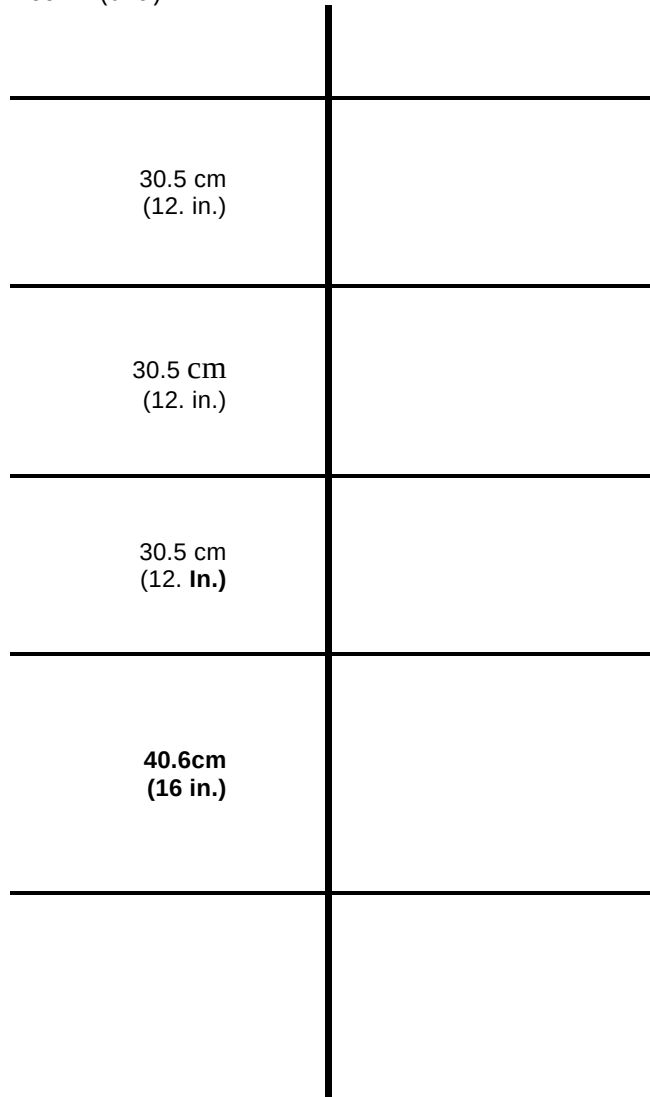


Figure V-2. **Crossed Yagi directional antenna for APT reception**

Figure V-3a gives the spacing, arrangement, and physical dimensions of the one set of elements of the antenna pictured in Figure V-2. An identical set of elements with the same dimensions and spacing are then arranged at right angles to the first set but located 5.1 cm (2 inches) behind them. This forms the crossed arrangement necessary for proper reception of circular polarized RF signals.

1.83 m. (6 ft.)



THIRD DIRECTOR

$$D_3 = D_1 - .05 D_1$$

$$D_3 = 87.4 \text{ cm (34.4 in.)}$$

SECOND DIRECTOR $D_2 = D_1 - .05 D_1$

$$D_2 = 91.9 \text{ cm (36.2 in.)}$$

FIRST DIRECTOR $D_1 = RA - .05 RA$ $D_1 = 96.8 \text{ cm (38.1)}$

RADIATOR 5520

RA (in Inches) = Frequency in MHz $RA = 101.9 \text{ cm (40.1)}$
REFLECTOR

$$RE = RA + 0.1 RA$$

RE = 112.0 cm (44.1 in.)

Figure V-3a. **Spacing, arrangement and dimensions of one set of elements of a crossed Yagi antenna for APT reception**

5-5

The main beam which supports the elements is made from a piece of 2.5 cm (1 inch) square aluminum tubing 1.83 meters (six feet) long. The elements are cut from 9.5 mm (three-eighths inches) diameter aluminum rods. These elements consist of three crossed sets of directors (DI, D2, D3). A pair of folded dipoles form the driven elements or radiators (RA) and a pair of reflectors (RE) are positioned behind the radiators. The length and spacing of all of these elements are dependent on the frequency that the antenna is designed to receive. All measurements given in Figure V-3a were calculated for a frequency of 137.5 MHz by formulas published in the ARRL Handbook for this type of antenna. The folded dipole radiators are similar to a design suggested in the Weather Satellite Handbook, available through the American Radio Relay League, 225 Main Street, Newington, CT 06111.

The first stage of construction requires measuring the correct spacing for the elements along the square beam. The first set of directors (D3) should be located about 12.7 cm (5 inches) from the end of the beam. The remaining element spacings should be drilled through both walls of the square beam. These holes should be as close to perpendicular as possible and centered on the flat surface. Another complete set of measurements and holes, following the same spacing as the first, should be marked and drilled. These, however, should be set 5.08 cm (two inches) behind the first and at RIGHT ANGLES to the first series. If possible, a drill press should be used. If the holes are correctly made, the aluminum rods should fit snugly.

The directors (DI, D2, D3) and reflectors (RE) offer no special problems. The aluminum rods forming these elements can be cut and pushed through the holes in the square beam so that they extend through the square equidistant on either side of the beam. There are a number of ways that these can be held in this position permanently. The simplest of these is to notch or crimp the rods on either side of the beam as close to the beam as possible using a large screwdriver and hammer. This will deform the rod enough so that it will not pass through the holes. Care should be exercised so that the rods are not bent.

r
101.9 cm (40.1 in.)



Figure V-3b. **Design of one radiator for the antenna shown in Figure V-3a**

5-6

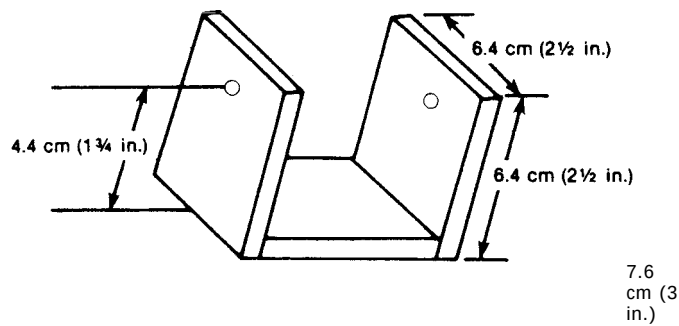


Figure V-4. **Plastic insulators for supporting open ends of the folded dipoles (two needed)**

The pair of radiators (RA) require a little more attention and care. The final design for one of the sets should look like the diagram in Figure V-3b. This requires two rods 2.08 meters (82.1 inches) long and positioned through the holes marked "RA" in Figure V-3a. These should be, one at a time, positioned so that they are centered and have equal extension on both sides of the square beam. The rods should then be crimped so that they retain their position. This rod is then bent 180 degrees at a point 50.9 cm (20.05 inches) from the center of the beam on both ends. A 3.8 cm (1.5 inch) wooden dowel can be held at this point and the rod bent around the dowel. Spacing between the two parallel portions of the dipole should be as close to 5.08 cm (two inches) as possible.

The open ends of this folded dipole are held in position by a plastic holder shown in Figure V-4. This plastic insulator should be constructed from 6.4 mm (.25 inch) plastic sheet with 9.5 mm (3/8 inch) holes that will accept the open ends of the folded dipole. The ends of the dipoles should be slid into the plastic holder first. Then the insulator should be drilled and mounted with metal screws on the flat portion of the beam. The second folded dipole, set at right angles to the first, is positioned in the same way. The final arrangement is shown in Figure V-5.

The details on connecting this antenna with the APT system receiver are discussed in the section "THE TRANSMISSION SYSTEM" beginning on page 5-14.

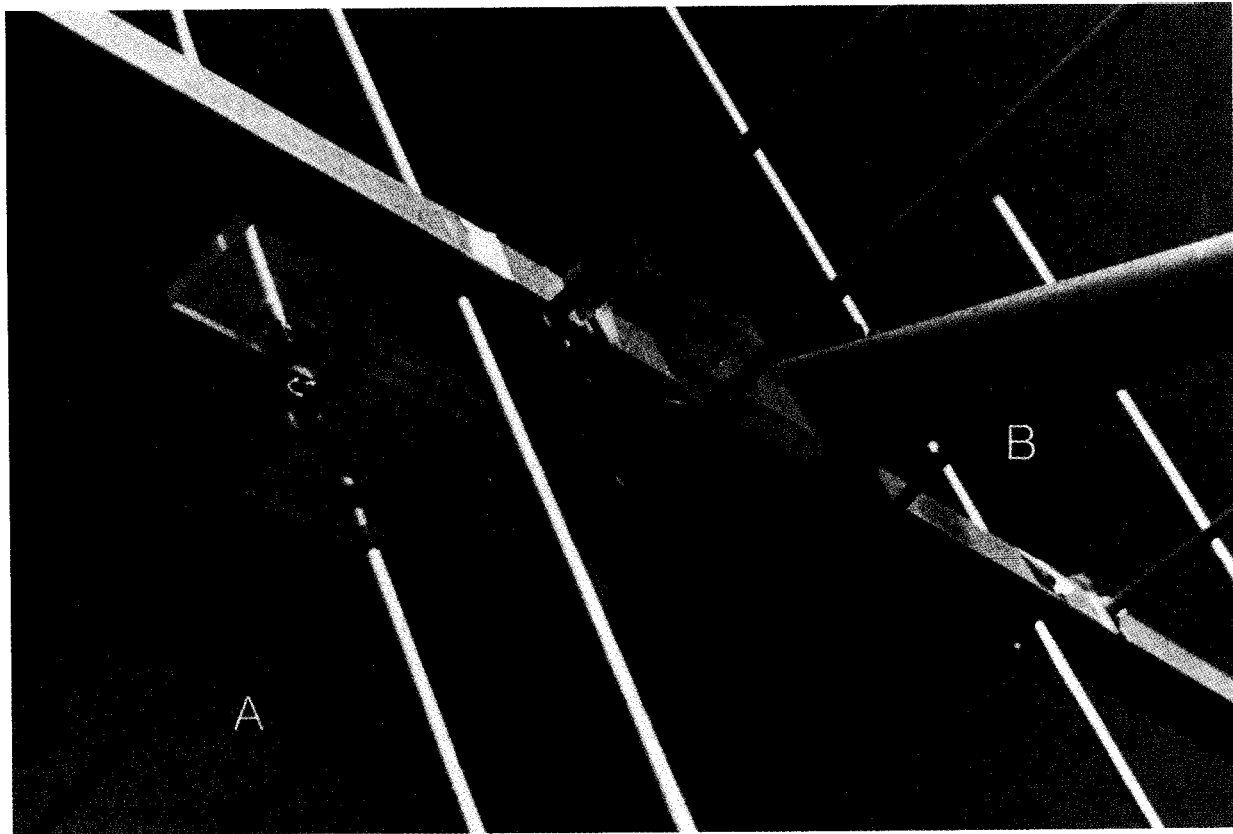


Figure V-5. **Detail--plastic holders supporting folded dipoles**

ANTENNA MOUNTING

The location of the antenna should be given careful consideration. If at all possible, it should be placed so that a clear view of the horizon is available in all directions. Consideration should also be given to a location where repairs and adjustments can easily be made. Long lead-in wires should be avoided.

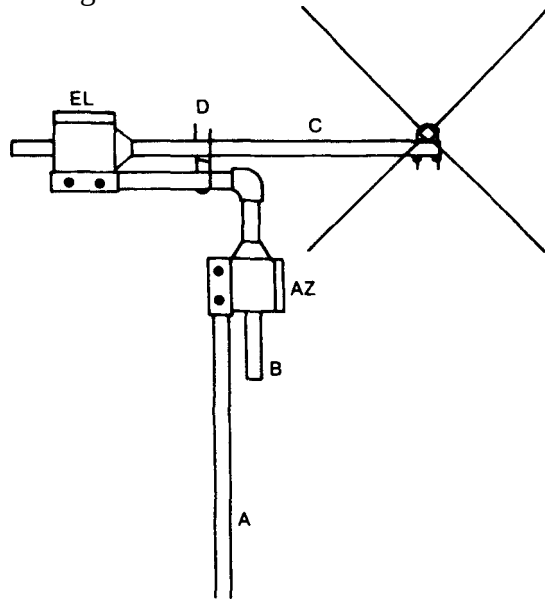
There are a number of mounting designs which allow azimuth and elevation antenna tracking of satellites. The design shown in Figure V-6 is one example that works well.

Steel pipe 3.2 cm (1.25 inch) diameter was used for all mounting supports. It can be found at most plumbing supply houses or electronic stores which sell antennas. Stores supplying radio amateurs or television antenna and cable system supplies can likely supply the antenna motors and control boxes.

5-8

Section A in Figure V-6 is approximately 1.52 m (five feet) long and is permanently mounted on the roof or location of choice. Standard antenna mounting brackets can be used, but the methods of mounting will vary with local conditions. An antenna motor (TV-type) is bolted to the top of section A. This motor serves as the azimuth (compass direction) motor. Section B is made from two, 0.61 m (2 foot) sections of pipe connected by a 90degree elbow.

One end of Section B is mounted into the azimuth motor. A second antenna motor is then bolted to the other end of Section B. This motor will support the antenna and turn it through various



B - Two, 0.01 m (2 foot) sections of mast pipe connected by a 90° elbow

C - 1.22 m (4 foot) section of mast or aluminum pipe

D - Support U-bolt

A third, 1.22 m (4 foot) section of

A - 1.52 m (5 foot) section of mast pipe degrees of elevation

EL - Elevation motor
elevation AZ - Azimuth motor

pipe (C), is mounted through the

motor. The antenna is mounted with U

Figure V-6. Antenna mounting design bolts to the other end of Section C. (See Figure V-7.) The antenna should be attached at its center of balance. This pipe can then be slid through the antenna motor until the weight of the antenna and the weight of the elevation motor counterbalance each other. A U-bolt with a supporting plate (D), is attached to C to support the weight of the antenna to take the stress off the bearings of the elevation motor. (See Figure V-8.)

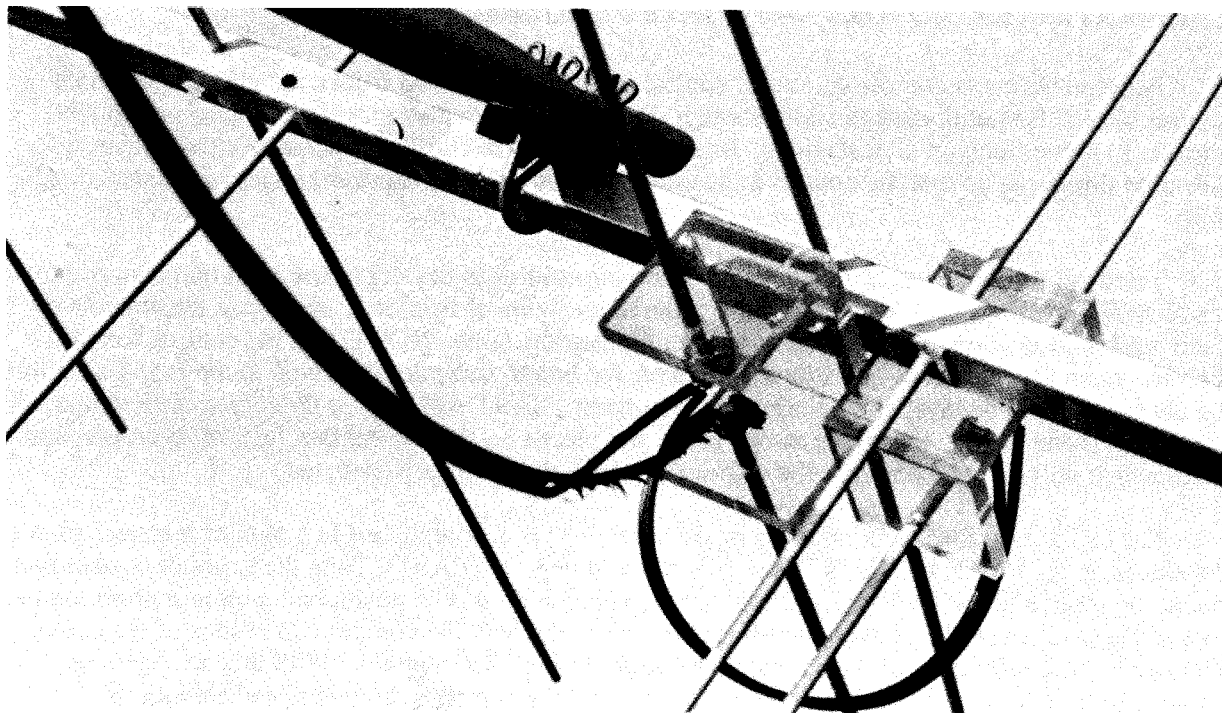


Figure V-7. Antenna mounting details

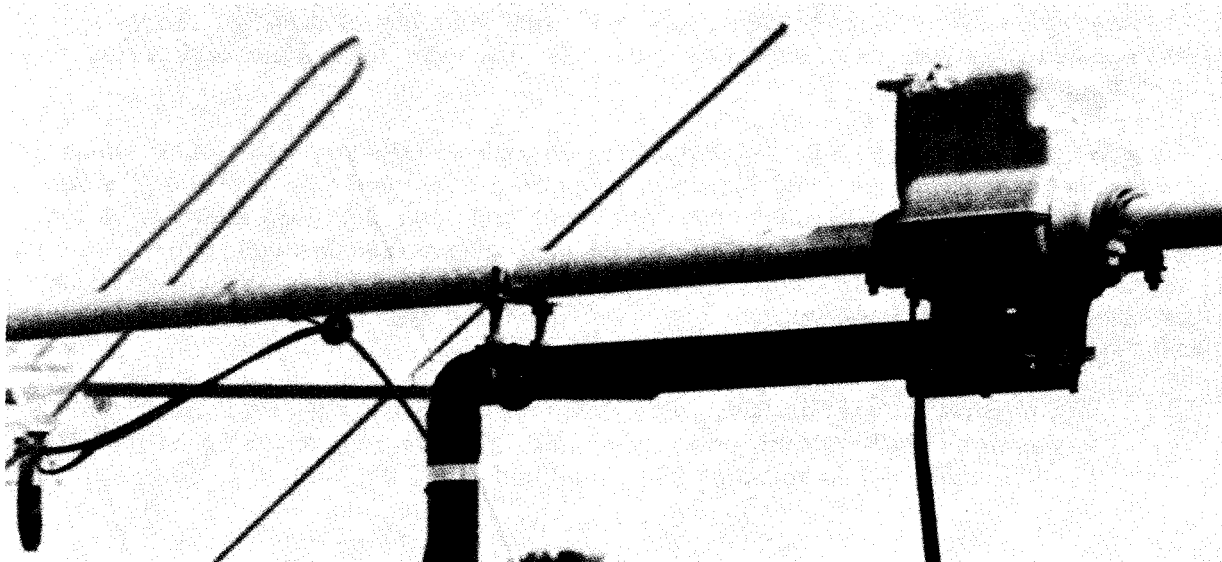


Figure V-8. U-Bolt support for antenna and elevation motor

After mounting is completed, motor control wires should be run from each motor to separate control boxes. It is important to allow enough slack in the wires and wire standoffs, to permit the antenna to move freely in all directions. It is then necessary to calibrate the antenna azimuth and elevation directions so that the control indicators will give accurate representations of antenna directions.

To adjust the elevation of the antenna, rotate the control indicators of the elevation control box to the NORTH position. At the antenna, loosen the motor bolts of Section C and rotate the antenna by hand until it points directly overhead and then retighten the bolts. NORTH on the control box will then represent 90 degrees of elevation. Whenever the control indicator is moved to the EAST position, the antenna should be level and pointing at the horizon. EAST will then be 0 degrees of elevation. A scale from 0 degrees to 90 degrees can be made and placed on the control box face between east and north which will give the operator the degrees to which the antenna is elevated.

The calibration for the azimuth (compass direction) is accomplished in a similar manner. First, the elevation control should be positioned to 0 degrees (EAST). Then the azimuth control box should be rotated to the NORTH position and the antenna should be positioned, pointing north, on the roof. Whenever the bolts of the azimuth motor are retightened, the compass directions of the control should be a true indication of the antenna's azimuth through 360 degrees. With this arrangement, it is possible to track any polar-orbiting satellite through all the compass directions and elevations.

Other Antennas for APT Reception

Other high-gain beam antennas may be purchased commercially along with a heavy-duty azimuth/elevation rotator (used for amateur radio antennas) that may be interfaced to the personal computer for automated tracking of the polar orbiting satellites. These commercial beam

antennas usually provide an electro-mechanical relay to switch between left and right-hand circular polarization, depending on the satellite signal. The gain of these beam antennas can approach 14 dB, and beam widths for VHF frequencies can be down to 20 degrees spacing. Combined with a preamplifier, the high gain and narrow beamwidth results in a high performance antenna system. It is not unusual to receive horizon to horizon coverage on a POES satellite pass (about 15 minutes for an overhead pass of the satellite).

The simple omnidirectional antenna shown in Figure V-9 can be constructed by modifying a commercial FM antenna with a pair of crossed, folded dipole elements, that can be found in many stores selling television and radio antennas. Such antennas are low cost, and made of thin aluminum tubing that can be cut to modified dimensions quite easily.

5-11

The antenna in Figure V-9 was modified as follows:

1. The length of the folded dipoles (A and A') was reduced by trimming the longer FM element tubing to 103 cm (40.3 inches) to provide an approximate $\frac{1}{4}$ wavelength match for the 137.5 MHz center frequency of the APT transmission.

2. Two reflectors (B and B') at right angles to each other were made from 6.4 mm ($\frac{1}{4}$ inch) diameter aluminum tubing, cut to 113 cm (44.1 inch) length. These were mounted 43.6 cm (17 inches) below and parallel to the folded dipoles. These reflectors create a broad beam antenna that, when pointed vertically, allows a wide angle

of antenna reception with no need for pointing toward the satellite as it passes over the ground station. However, as noted before, the convenience of this design is offset by the fact that such an antenna offers little, if any, signal gain and reduced coverage compared to a higher gain, directional antenna.

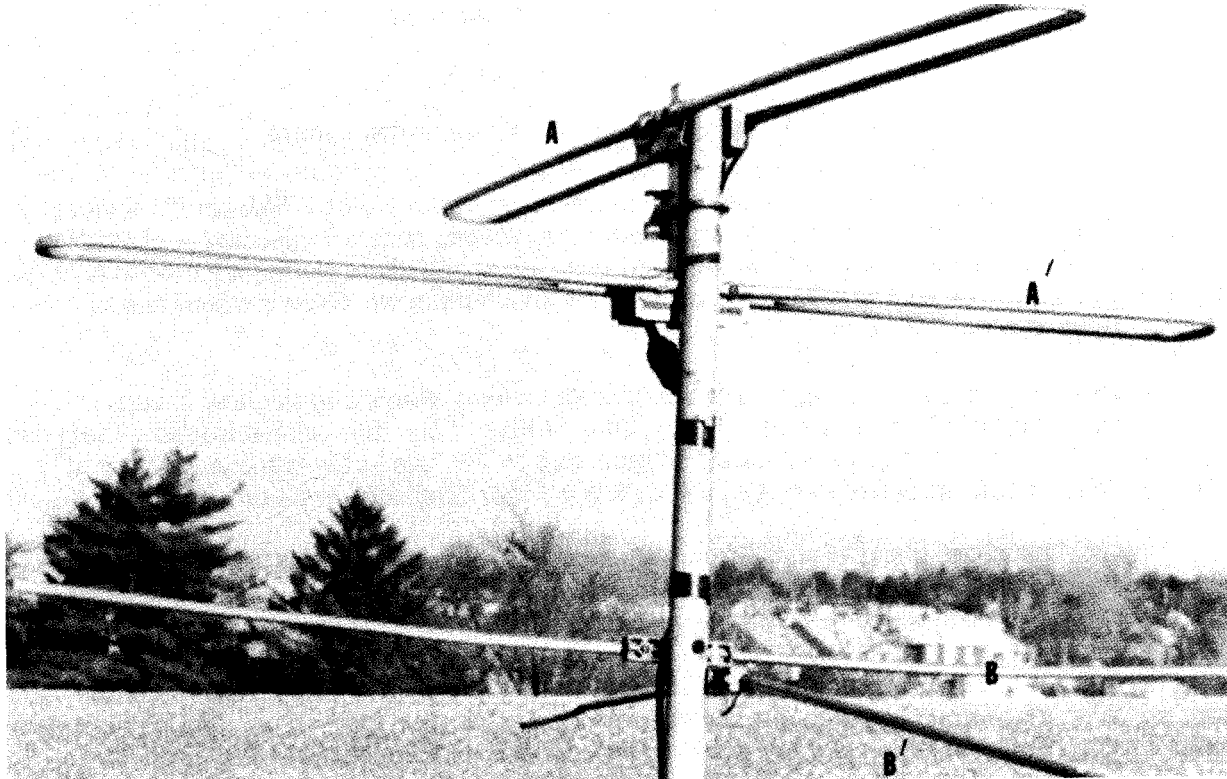
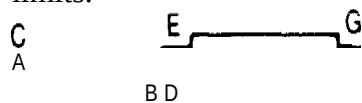


Figure V-9. **Modified FM antenna for omnidirectional APT reception**

THE TRANSMISSION SYSTEM

The components of the transmission system which carries the RF signal from the antenna to the radio receiver are shown in Figure V-10. Proper construction of this portion of the direct readout station is important to ensure that radio frequency signal losses do not exceed acceptable limits.



- A 300 ohm TV lead-in, 1.52 m (five foot) section
- B 300 ohm to 75 ohm matching transformer
- C - F59 connector
- D - RG58U, short section 30.5 cm (approx. 12 inches)
- E - PL 259 connector
- F - Vanguard Lab Preamplifier (Model 102W)
- G - PL 259 connector
- H - RG8U coaxial cable to radio receiver

Figure V-10. **Components antenna-to-receiver transmission system**

At the antenna, the open ends of one of the radiators are connected by a 54.6 cm (21.5 inch) length of 300 ohm TV lead-in wire to the open ends of the second radiator. (See part A of Figure V-8). To ensure good electrical contact; 1.3 cm ($\frac{1}{2}$ inch) automobile hose clamps are used to hold the stripped ends of the TV lead-in wire in contact with the aluminum rods. Other methods can be used as long as electrical contact is guaranteed.

A second 1.52 m (5 foot) section of this 300 ohm wire is attached by the hose clamps to the ends of one of the folded dipole radiators. (See part B of Figure V-8). This section is used to carry the signal from the antenna radiators and should be supported by TV stand-offs with enough slack allowed so that the antenna is free to move in all directions of azimuth and elevation.

To avoid excessive loss of signal from the antenna to the radio receiver, low loss 50 ohm RG8U coaxial cable must be used for the transmission line leading through the building to the receiver. Also, most receivers will require a 50 ohm impedance match between the antenna and the receiver.

For a better impedance match between the 300 ohm TV line and the 50 ohm RG-8U, a 300 to 75 ohm matching transformer has been inserted between the 1.52 m (5 feet) section of TV line and the RG-8U cable. This type of transformer was used because it is inexpensive and easily available in most TV appliance or electronics stores. Of course, a 300 to 50 ohm transformer would offer a better match and this type should be used, if available.

5-13

Since high quality, noise-free signals from the satellite are the desired goals of a direct readout station, it is recommended that a preamplifier be incorporated into the transmission system. These preamplifiers offer less than 0.5 dB noise for about 20 dB gain and can be ordered pretuned to 137.5 MHz which is the center of the frequencies of interest. The bandwidth is sufficient to cover all the APT frequencies. Purchase of this component will add about \$60.00 to the cost of the station, but it will give a noticeable improvement to the quality of the APT signal.

The preamplifier, if used, should be placed in the 50 ohm RG-8U line close to the antenna. Most commercial preamplifiers are weatherproof, and can be placed in exposed locations. To insert the preamplifier, the RG-8U cable should be cut and two male PL 259 connectors placed on the open ends. These in turn will be mated to the input and output female connectors on the preamplifier.

Most preamplifiers have provisions for powering the electrical components through the coaxial line rather than running a separate power line to the preamplifier. They have components to provide +12 volts to the center conductor of the RG-8U cable at the radio receiver. Some radios can be obtained with these power components already in place. All connector plugs in the transmission line should be installed carefully so that good electrical contacts are made. Any connectors exposed to the weather should be weather protected with some type of sealant (i.e. "Coax-Seal") so that water cannot enter the connectors or cable and cause electrical shorting. If this does happen, serious signal loss will occur.

Antenna Systems for GOES WEFAX

To receive WEFAX from GOES at 1691.0 MHz requires a different antenna system from the ones described for receiving APT from the polar orbiting satellites. The two primary reasons for this are the relatively lower signal strength received from geostationary satellites 22,500 miles above the Earth and the considerably higher frequency of the FM radio signal used to transmit the WEFAX data. Also, continuous tracking of the antenna is not required for

geostationary satellites. Once properly aligned to the satellite downlink signal, the antenna is locked into position and rarely requires any further adjustments.

The most common approach to these problems has been to use a parabolic or "dish" reflector to collect and concentrate the weak signals into a smaller receiving area referred to as a "feed horn" that is placed at the focal point of the reflector. The amount of signal gain at the feed horn area is proportional to the size of the collecting area of the dish. This, and the use of electronic low noise preamplification of the signal, make it possible to receive noise free WEFAX transmissions. This same approach has been used with the popular Earth Stations that are used to receive satellite television from the geostationary television satellites that have proliferated in recent years. These television satellites, however, transmit signals that are quite different from the WEFAX of the weather satellites in both frequency and format. The feed horn construction and electronics are different but the parabolic reflectors are the same and can be modified for WEFAX reception if available.

5-14

The diameter of the dish will determine the overall gain. Typically, for noise free reception from the GOES satellites, a gain of at least 25 dB is required from the dish and preamplifier. A 2-3 foot dish is small and easy to handle, but offers minimal gain and a very wide beamwidth which is susceptible to interference from signals of other satellites. A dish of 4 foot diameter can provide adequate gain with a narrower beamwidth. A 6 foot dish is about optimal for WEFAX reception with gain more than 25 dB and very manageable beamwidth. Table V-1 compares the WEFAX dish diameter and expected signal gain.

<u>Dish Diameter</u>	Gain
2 feet (0.6 meters)	18
4 feet (1.2 meters)	24
6 feet (1.8 meters)	27.5
10 feet (3.0 meters)	32

Bi

Table V-1. **Parabolic dish antenna diameter versus gain**

The one disadvantage of the larger (10 foot or larger) dishes are their very narrow beamwidth. If the dish is not aimed very accurately at the satellite, small drifts in the satellite orbit can cause the satellite to move out of the antenna pattern and hence degrade received signal quality.

An excellent treatment of this type of antenna design can be found in the article "Be A Weather Genius-Eavesdrop on GOES" by Ralph Taggart, published in the November 1978 issue of 73 Magazine for Radio Amateurs, if you can still find a copy at a library or other source. This article also contains information on the use of 1691.0 to 137.5 MHz down converters to bring the WEFAX signal to a frequency range that is usable by the standard APT radio receivers.

Most WEFAX systems employ a feedhorn and a 1691 MHz down converter in a weatherproof box. The down converter changes the 1691 MHz WEFAX signal to a more usable

137.5 MHz signal. Losses in the coax cable are rather high at a frequency of 1691 MHz. By converting this signal to 137.5 MHz, longer runs of less expensive coaxial cable can be used from the WEFAX antenna to the radio receiver tuned to 137.5 MHz.

Antennas for HRPT and GVAR Systems

Antenna systems for the HRPT and GVAR ground stations will be discussed in the chapter on "Advanced Direct Readout Systems."

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VI. RADIO RECEIVERS FOR SATELLITE DIRECT READOUT

One of the key components of a direct readout station is the radio receiver. The type of radio receiver used for the satellite downlink will determine the ultimate quality and resolution of the APT and WEFAX imagery. Radio receivers for direct readout stations are similar to the many FM "high band," solid state receivers used to receive police and fire department transmissions, and NOAA weather radio broadcasts. In fact, many of these receivers could be modified for direct readout service. Basically, any receiver must meet certain minimum requirements for adequate video reception. These requirements are set by the nature of the APT signal transmitted from the satellite. The APT transmission parameters for the polar orbiting weather satellites of the United States, Russia, and China are given in Table VI-1.

<u>Parameters</u>	<u>U.S. POES</u>	<u>Russia Meteor/OKEAN</u>	<u>China Feng-Yun</u>
<u>Frequency</u>	137.50, 137.62 MHz	137.40, 137.85 MHz	137.795 MHz
Carrier Modulation	Analog AM/FM	Analog AM/FM	Analog AM/FM
Transmit Power	5 Watts	5-10 Watts	5 Watts
Antenna Polarization	Right Hand Circular	Linear and Left Hand Circular	Left Hand Circular
Carrier Deviation	+/- 17 KHz	+/- 15 KHz	+/- 17 KHz

TABLE VI-1. APT Transmission Parameters of the Polar Orbiting Satellites

There are five factors of primary importance in a direct readout station receiver:

- The frequency of the transmitted APT signal
- The type of RF signal modulation
- The bandwidth of the transmitted signal
- The sensitivity of the receiver
- The selectivity of the receiver

The "satellite band" for the APT from polar orbiting satellites is between 137 and 138 MHz. This is a narrow section of frequencies located between commercial aircraft allocations and the 2-meter amateur radio band. Presently, NOAA-12 is transmitting at 137.50 MHz. NOAA-14 is broadcasting at a frequency of 137.62 MHz. The Russian satellites (Meteor, OKEAN, and SICH) are currently using the frequencies of 137.40 MHz and 137.85 MHz. Future Advanced TIROS-N series satellites are planned with APT signals at the same general frequency ranges. All these satellites are transmitting with Frequency Modulation (FM) with an underlying subcarrier that is amplitude modulated. Based on these transmitting frequencies, it will be necessary to obtain an FM receiver that is capable of operating through this range of radio frequencies.

The most practical (and least expensive) approach for a direct readout station is to use a radio receiver that has crystal controlled tuning. Using this type of receiver, after the crystals of the proper frequency are placed in the radio, no further tuning should be necessary; and the radio will be on frequency for proper reception. Also, many radios of this type will accommodate a number of crystals of different frequencies with a switch for frequency selection.

Crystals of the proper type can be purchased from a number of manufacturers. Many of these advertise in popular radio magazines, and some have toll-free telephone numbers for placing orders. The crystals for the APT frequencies will probably not be in stock, and there will be a few weeks before they will be available after the order is placed. The type and model of the receiver should be included with the order. Newer radio receivers have a built-in frequency synthesizer. Crystals are not required. The frequency is simply punched in via a keyboard on the radio or through the use of tuning switches. One advantage of a synthesized receiver is that one does not have to purchase additional crystals if the frequencies for APT reception are changed. Many newer radios also have the capability to automatically scan a set of frequencies for active signals, allowing for automatic reception of APT imagery from multiple satellites at different times of the day.

The bandwidth of the APT receiver is also an important factor in receiving good video products from the weather satellites. In receivers the bandwidth is established by a filter in the IF (intermediate frequency) stage. To reproduce good APT pictures, the bandwidth must be wide enough to pass the entire signal or distortion and loss of picture resolution will occur. Too narrow an IF bandwidth and the blacks and whites in the imagery will be clipped. Excessive bandwidth, however, will introduce excessive noise into the signal. The APT signal bandwidth is influenced by two factors, the satellite transmission deviation and the Doppler effect, which cause a frequency shift as the rapidly moving satellite approaches and passes the ground station. The signal deviation of the TIROS series transmission is ± 17 KHz. It is ± 15 KHz for the Meteor series. The Doppler frequency shift for these satellites is about ± 4.5 KHz during an overhead pass, where the effect will be most severe. Using these parameters, for ideal APT signal reception, the bandwidth of the receiver should be about 40 KHz (± 20 KHz). A signal received on a typical police-type scanner with a ± 7.5 KHz (15 KHz bandwidth) will be very distorted and produce poor imagery. It is possible to modify these receivers by changing out the original IF bandwidth filter with one closer to 30-40 KHz deviation and receive adequate imagery from both the POES and Russian satellites.

The sensitivity of the receiver is of prime importance in APT signal reception. Since noise-free signals produce the best satellite pictures, it is essential that the noise level be kept at a minimum. Sensitivity refers to the ability of the receiver to detect weak signals through the

noise level of the receiving system which includes antenna and internal thermal noise of the receiver. Generally, this is referred to as the signal to noise ratio-where the signal strength is given in microvolts and the noise in dB (decibels). A good receiver for APT direct readout stations will have a sensitivity of about 0.2 to 0.3 microvolts for 20 dB of quieting. However, with the addition of a low noise preamplifier, receivers with less sensitivity, on the order of 0.6 microvolts, can produce noise-free signals when used with the antenna and transmission systems described in this publication.

In most cases, acquiring a receiver for the APT direct readout station will be influenced by cost. Since the basic requirements of frequency, bandwidth, and sensitivity are not unreasonable, a radio adequate for receiving APT should not introduce cost factors out of line with most personal budgets. Generally, there are three practical ways of obtaining radio receivers:

1. Purchase a commercial receiver (either a kit or assembled) specifically designed for APT
2. Modify a scanner receiver for the correct bandwidth
3. Modify a surplus high-band commercial receiver

COMMERCIAL RECEIVERS

The simplest, most effective approach is to purchase a commercial weather satellite receiver. There are several vendors who market crystal-controlled and fully synthesized receivers optimized for the 137 MHz weather satellite band. References to commercial vendors are discussed at the back of this publication. One such vendor is Hamtronics, Inc. This firm manufactures weather satellite receivers in kit form or *fully* assembled. An example of their crystal controlled receivers is the R139 (Figure VI1, main circuit board and assembled receiver) and is typical of such APT receivers.



Figure VI-1. Crystal controlled receiver

The R139 Weather Satellite receiver is a low cost, crystal controlled receiver featuring high sensitivity (0.2 microvolts typical) and selectivity for the 137 MHz band. This receiver uses special wideband filters for 3.8 KHz IF modulation acceptance and low video distortion from both the U.S. TIROS and Russian Meteor spacecraft. The unit can automatically scan up to five channels, and lock on to any one active satellite frequency. The scan circuit contains a tape

recorder control to allow automatic and unattended search and recording of satellite signals. The R139 can be purchased *fully* assembled or in a kit form.

6-3

Another approach to receiver design is a synthesized weather satellite receiver that is controlled from a personal computer. The PC-137 Computer Controlled Receiver (Figure VI-2) manufactured by Quorum Communications is a frequency synthesized receiver designed specifically for the reception of NOAA, Russian, and Chinese APT weather satellites. All the receiver functions can be controlled from the software menu on the PC, and constitutes a fully automatic system when used in conjunction with an APT image capture card. The power for the receiver is provided by the host personal computer. The receiver operation is controlled by the software and allows program control of the following features:

- User programmable frequencies from 136 to 141 MHz
- On-screen numerical signal strength meter
- APT preamplifier on/off power Visible sub-carrier
- lock with alarm Input pins for WEFAX down
- converter signal input User definable gain control
- Scheduling of scanning functions based on preset time or signal **frequency**

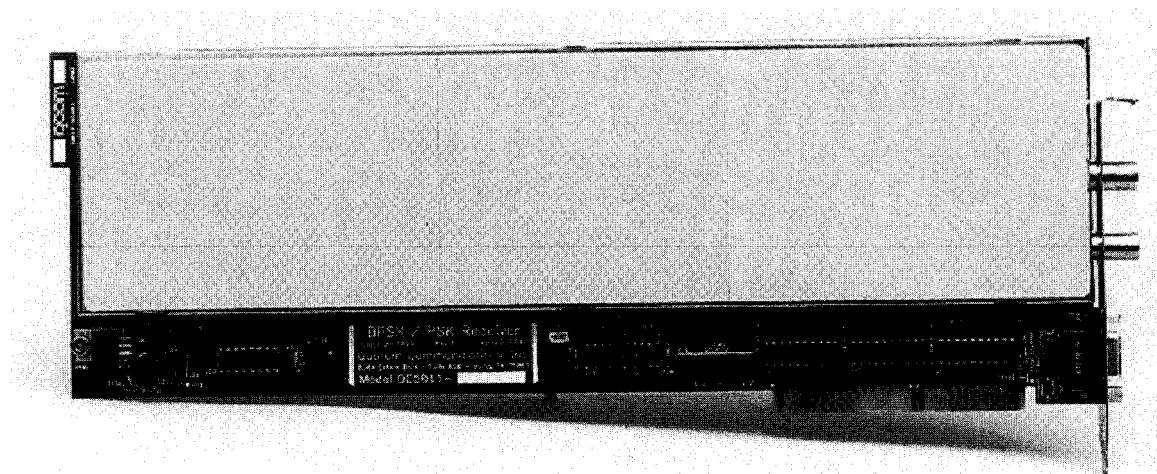


Figure VI-2. A satellite receiver on a PC card

The PC-137 is placed into a standard PC adapter card slot. It can be used in any IBM PC compatible computer (from the old PC/XT through the newest Pentium computers). The coax cable to the APT antenna and/or WEFAX down converter is attached to the back of the card, and the software provides all the functional operations. If a WEFAX down converter is not used, then a second VHF antenna can be connected to the connector on the back of the unit. By having two RF inputs, a user could connect an omni-directional antenna and a beam antenna, if

Figure V-3 depicts a commercial, broadband receiver by Icom. The Icom R8500 is a frequency synthesized general coverage scanning receiver that may be directly controlled by the personal computer. This is a high-end commercial unit that covers both the VHF APT weather satellite band, as well as the WEFAX, GVAR, and HRPT S-band frequencies of 1.6 and 1.7 GHz. The receiver is fully programmable either in manual mode or via the PC. Modification kits are available to change the IF bandwidth in FM narrow-band mode to 40 KHz. Multiple audio outputs are available for analog or digital recording of the satellite signals. Most high end receivers, such as the Icom, are in the \$ 500 to \$1000 price range, but provide many features allowing reception of several different direct readout data products, and other radio services.



One economical approach to obtaining a weather satellite receiver is to modify a new or used police or utility band scanner. Several different types of scanners exist in the used marketplace, including crystal controlled scanners, programmable scanners for public service bands, and the wider-coverage commercial scanners.

provide adequate signal quality for APT imagery. A good preamplifier is recommended as the front-end sensitivity of these earlier model scanners was generally poor.

Programmable scanners made by Radio Shack, Uniden, and other manufacturers are also prime candidates for lowcost APT receivers. Many of these scanners already cover the 137 MHz

frequency range. It is simply a matter of punching in the correct frequency with the keypad and modifying the IF filter. One brand of scanner, manufactured by Uniden, simply requires the 10.7 MHz IF ceramic filter to be removed, and replaced with a 0.01 microfarad capacitor to bring the IF bandwidth to 40 KHz. This procedure normally takes less than thirty minutes and can provide good performance for a APT receiver. Once again, a good preamplifier, preferably mounted at the antenna, is recommended for higher gain and sensitivity.

SURPLUS HIGH BAND RECEIVERS

Many police and fire departments have been retiring the commercial FM units designed primarily for the VHF frequency ranges, in favor of the newer 900 MHz cellular or trunked radio systems. These surplus units are of high quality, and could be converted to the 137 MHz frequency with minimal effort. Often these units may be obtained at very low cost or even free for schools. Typically the IF frequency filters need to be changed for 30-40 KHz, and some retuning of the front-end circuitry required for peak performance at 137 MHz. Local ham radio operators can often assist with conversion of these units.

PREAMPLIFIERS

Due to the fairly low signal strength from the POES satellites, receiving stations generally require a high quality preamplifier. The preamp should have a reasonable amount of gain and a relatively low noise figure. Gain specifies how much signal is amplified, and the noise figure is a measurement that specifies the amount of noise the amplifier adds to the original satellite signal. A noise figure of 1 dB and a gain of 15 to 20 dB is more than adequate for APT reception.

The general rule on preamplifier gain is to use only enough gain to set the system noise figure and overcome the loss in the coaxial cable that connects the preamp to the receiver. Any excess gain contributes to receiver inter-modulation problems. Inter-modulation (also called intermod) is a common problem for receiving stations located in larger cities. Intermod is created in the receiver due to excessive preamplifier gain. If you hear aircraft radios or ham radios coming through the satellite receiver, then intermod is usually the problem.

Typically, signal losses in a 100-foot run of RG-8 coax can be as much as 50%, depending on the frequency of the received signal. Preamplifiers help boost the initial signal strength prior to traveling down the coax line to the receiver. Modern preamplifiers use either JFET or Gallium Arsenide JFET transistors. These units provide high gain (20 dB typical) with low noise figures (0.8 dB). Normally the preamps are manufactured in a small metal enclosure

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with either PL259 or N connectors at both ends for the attachment of coax cable to the antenna and the receiver.

Preamplifiers mounted at the antenna will require both power and waterproofing. Either a separate +12 volt line may be run externally to the preamplifier, or, the coax feed line can carry both the DC power and the RF signals. Many modern weather satellite radios can provide the +12 volts to the preamp directly from the radio through the coax lines. Waterproofing can be provided with rubber gasket seals around the metal housing and antenna connectors. Commercial preamplifiers can be purchased for around \$60, and can be provided in weatherproof metal enclosures for in-line mounting close to the antenna.

DOWN CONVERTERS FOR GOES WEFAX

The WEFAX signal from the GOES satellite is received at a frequency of 1691 MHz. A down converter is used to convert the 1691 MHz UHF signal to a more manageable frequency by reception by a VHF receiver. The 1691 MHz signal is typically mixed with a local oscillator frequency in the down converter to yield an intermediate frequency of 137.50 MHz. This down converted IF signal is then fed to the APT receiver's antenna jack. Thus, through the use of a down converter, the same radio may be used for both APT and WEFAX reception.

The down converter noise figure and gain are two important specifications that greatly affect the received WEFAX image quality. The lower the noise figure (which is actually a measure of noise generated within the circuitry of the down converter) the better. Since the received signal is from space which contains very little background noise at 1691 MHz frequencies, the down converter noise is the limiting factor in system sensitivity. The amount of internally generated noise also affects the size of the antenna that is required to receive a noise free image. Using a down converter with a 5 dB noise figure requires a much larger receiving antenna than a system with a 1 dB noise figure.

The gain of the down converter refers to the conversion gain from the RF input connector to the IF output connector. A conversion gain of 40 to 45 dB will allow cable lengths of up to a few hundred feet from the down converter IF output to the VHF receiver input. Normally a small type coax cable such as Belden 9311 is used to connect the IF output from the down converter to the APT receiver. A coax antenna switch, mounted inside at the ground station, will allow switching the 137.5 MHz receiver between the WEFAX down converter for GOES reception, and a 137 MHz antenna for APT image reception.

Recording Satellite Signals from Weather Satellite Receivers

Satellite images can be produced on most display systems as the signal is being received (real time). An audio tape recorder can be used to save these transmissions for later analysis or to archive data of special interest. Most tape recorders, however, do not have enough accuracy in motor speed to assure proper synchronization of the image on play back. This can be

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overcome if a stereo tape recorder is used and a synchronization reference, such as a 2400 Hz tone, is recorded on one of the audio channels while the satellite transmission is being recorded on the other channel. Then, on play back, the display system can use this reference to track slight changes in the motor speed and adjust the synchronization so that the satellite image will be properly aligned to produce a coherent image. Most computer display systems are designed with internal image synchronization and can also use recorded satellite transmission.

The use of a tape recorder with extreme variations in motor speed during replay will cause the picture to drift or to have wave-like variations from border to border even when using a synchronization tone on the second channel. For this reason, the tape recorder must have a reasonably constant motor speed. The specifications that measure the amount of variation from a constant speed are called "wow and flutter" and is expressed in percentage values. Recorders with a wow and flutter around 0.3% will work well with APT and WEFAX if a sync tone is used.

Tape recorders with the required specifications for use in the APT and WEFAX station are available in both cassette and open reel formats. The cassette format offers the advantages of ease of operation, convenient storage and cataloging of tapes, and a more compact size.

The open reel format is a bit more clumsy to operate and requires a little more shelf space than the cassette. Many open reel recorders provide a choice of tape drive speeds. A two speed recorder will give the option of 3-3/4 ips (inches per second) and 7-1/2 ips. A three speed model will add 1-7/8 ips, or 15 ips to these choices. The speed choices will allow the original 120 lines per minute transmission to be reproduced in a different format. For example, if a 2400 Hz motor synchronizing tone is recorded at 7-1/2 ips and replayed at 3-3/4 ips, a 1200 Hz tone will be produced driving the FAX or other display system at half the speed.

It is useful to have separate level controls for both record and playback on each channel. Some recorders have level controls which affect record only and provide replay at a fixed volume. Volume control on the playback is most useful for matching levels with the display inputs. Level meters are also useful in giving the station's operator a visual reference for duplicating or improving results.

A tape recorder which has the required specifications of constant tape drive speed, level controls, and meters will normally have excellent specifications in terms of frequency response. However, the video signals of the APT and WEFAX are constant frequencies in the middle range of the audible spectrum. The wide frequency response of most of today's high fidelity tape decks generously exceeds the requirements of the APT and WEFAX system. A high fidelity feature which may have some bearing on the performance or quality of the pictures is that of reproducing accurate dynamic levels since the APT and WEFAX video signal produces light and dark areas of the photograph corresponding to soft and loud variations in the level of the tone. Users report that newer digital audio tape (DAT) recorders provide a good platform to record the APT and WEFAX signals with little or no distortion in the video image. Users have also had

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good results using video recorders, since these usually have excellent wow and flutter specifications.

Most tape recorders will provide the user with the ability to monitor the tape while it is being recorded. This is accomplished by the placement of a separate playback head immediately beside the recording head and "playing" the tape a fraction of a second after it has been recorded. This monitor signal can be fed directly to the display system and an image can be produced in real time while the satellite is passing over the station. The recorded tape is not affected by the monitoring and additional images can be made by rewinding the tape to the point of the beginning of the transmission and replaying the recorded signal and synchronizing tones into the display system.

The APT signal from the NOAA operated TIROS Series satellites carries two images multiplexed from two different spectra, usually visible and infrared during daytime passes. These two pictures can be reproduced side by side on most display systems. When this is done the volume setting which is suitable for the visual image may cause the IR image to be too light or, if a volume setting is used to view the IR image the visual image may be too dark. The use of tape recorded passes will enable both images to be reproduced properly by using two separate replays of the tape and adjusting the volume accordingly.

One additional option for recording satellites signals is to use a standard sound card and associated software found in many of today's personal computer systems. The sound card has a digital signal processor that can store audio signals as a digital data stream, and play them back as analog audio output. The audio output from the receiver may be fed directly into the sound card and the signal recorded as a . WAV file on the hard drive. Recording audio signals as digital files requires a lot of hard disk space, so a full 15 minute satellite pass would take many megabytes of hard drive storage. But, the advantages over a tape recorder would be a more accurate representation of the original signal (no tape flutter to distort the signal) with little or no noise imparted on the signal by the recording system.

VII. DEMODULATION AND DISPLAY OF APT AND WEFAX IMAGERY

The next major component of the direct readout station is that of demodulation and display of the imagery. Once the signal is received from the POES or GOES satellites, the audio tones must be converted or demodulated to represent varying levels of visible and infrared energy as processed by the satellite radiometer. Previous editions of this publication discussed using facsimile machines and electrostatic recorders to demodulate and display the APT and WEFAX imagery. Computer display systems are now the most common method of displaying weather satellite images. Improved high resolution graphics hardware, increased computer speed and memory, high quality software programs with sophisticated image analysis processes are now available at costs that were unavailable only a few years ago. Because of the great variety of computer systems available or under development, only a general discussion of this subject is possible. However, some computer features that are required for satellite direct readout are examined, which can guide the user in selecting a computer that will meet their needs.

The diagram in FIGURE IV-1 shows a generalized view of the hardware components that are found in most personal computer APT and WEFAX systems. At the ground station radio receiver, the satellite transmissions are detected as a 2400 Hz amplitude modulated (AM) signal transmitted at either 120 or 240 lines per minute from the TIROS or GOES satellites. At this point the image exists as an analog representation of the original image created by the satellite's imaging instrumentation. The varying amplitude can be measured as a varying voltage having a discrete voltage range. The 2400 Hz tone, referred to as the video subcarrier, carries the image as a function of its amplitude. Two electronic processes must be accomplished before this analog image can be managed within a computer system:

1. The 2400 Hz subcarrier must be removed and only the amplitude variations of this carrier, which is the actual image, allowed to pass. This process is known as demodulation and is necessary so that the 2400 Hz, which in itself contains no information does not become a part of the finished image.
2. The demodulated video, in the form of a varying voltage, must be changed into relative digital values so that this data can be handled in the digital domain of the computer. This step in the process can be accomplished by an analog to digital converter (A/D) which is built to detect a voltage at a given instant and represent that reading as a binary digit. In 8- bit computer systems this will be a value between 0 and 255. This digit can then be stored in computer memory and the next conversion made. Each of these digital values then becomes a discrete element of the image and is referred to as a pixel or picture element. It is important to note that the speed or frequency of the sampling process will influence resolution of the image and the relative width of each scan line but is limited by the resolution of the original data.

Two additional steps are needed in order to display these digital pixels as a coherent image on the computer video monitor. Both of these require software programs written specifically for the computer and graphic display hardware that is available.

1. Each digital picture element must be assigned a specific intensity or brightness proportional to the original amplitude of the image. In black and white displays this can be used to form a linear gray scale or, in instances where enhancement of a certain portion of the image is desirable, other intensities can be used. Color enhancement can be accomplished by assigning specific colors to ranges of digital values.

2. The picture segments, or scan lines, must be precisely aligned to form a final coherent image. This requires that the beginning of each scan line can be recognized by the software and positioned in the proper location on the monitor screen. Hard copy of the images can be made by photographing the monitor screen or by special graphic printing programs on the computer.

Purchasing a commercial satellite computer display system is probably the most viable alternative in setting up a direct readout station. If a computer is already available, the cost of the additional hardware and software is normally not prohibitive. The commercial direct readout systems now available have been designed for a variety of computers (IBM PC compatible, Apple Macintosh, Commodore Amiga, and even some Unix systems) and have many different features. A partial list of vendors is available from the resources listed in the Appendices. Some features that can be expected from these commercial systems are:

1. Both APT and WEFAX capabilities
2. Capture and display U.S. POES, GOES, Russian Meteor, Chinese Feng Yun, METEOSAT, GMS, and OKEAN/SICH satellites
3. Automated image ingest and storage in various graphic file formats
4. Color enhancement of images
5. NOAA/NESDIS IR enhancement curves and manipulation
6. Automatic IR channel temperature calibration
7. Zoom and pan features
8. Image animation
9. Built-in satellite prediction and tracking routines
10. Scheduling features for unattended satellite image capture
11. Automatic longitude/latitude and geopolitical gridding
12. Some of the newer systems provide an input jack for a Global Positioning Satellite (GPS) receiver to input the station's exact location, altitude and precise local time directly to the satellite receiving system

Although the exact configurations of commercial APT and WEFAX systems will vary depending on the computer type and features offered, the basic minimum computer requirements for a typical 113M PC APT/WEFAX system would include:

- IBM PC compatible with 80486 processor 8-
16 MB of random access memory
540 MB hard disk drive

- 3.5 inch 1.44 MB floppy disk drive

- A VESA compatible video graphics card capable of operation in 1024 x 768 x 256 color mode

- 1 open 8 or 16 bit ISA or EISA adapter slot available for the demodulator card

This personal computer configuration is fairly standard in today's marketplace and would provide room to grow for future expansion. Of particular importance is the quality of the video display adapter. The received APT imagery is normally digitized by the demodulator card as 8 bit data, or 256 shades of gray scale. The computer display system should have at least 256 colors or shades of gray, with a minimum resolution of 640 pixels per line, with 480 lines. Displaying APT or WEFAX data in less than 256 shades of gray scale will result in poor image resolution. Current day personal computer systems are usually capable of displaying 256 shades of gray scale with up to 1024 pixels per line and 768 lines per screen.

The previous chapter discussed receivers, whether external or built on a card that can be inserted into the computer. As noted, it is now possible to purchase plug-in cards that have both an APT receiver and demodulator on a single card. A separate 1691 MHz down converter, mounted near the WEFAX antenna, is required for WEFAX image reception.

Following the physical installation of the demodulator card in the system board of the personal computer, cables are connected from the receiver to the APT preamplifier and antenna, and the WEFAX down converter and dish antenna. In systems that do not have a built-in APT receiver, a cable must be installed between the audio output jack of the receiver and the audio input jack of the demodulator card.

SETTING UP AND USING DIRECT READOUT SOFTWARE

APT and WEFAX software programs generally have four or five main functions. These would include:

1. Initial Configuration and System Setup
2. Satellite Image Capture and Scheduling
3. Satellite Prediction and Tracking
4. Viewing and Enhancement of Satellite Imagery
5. Image Animation

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After some initial configuration and testing, the user has a choice of capturing new satellite images, displaying and enhancing images already in memory or stored on the hard drive, creating weather animations from a series of stored images, or predicting when a particular satellite will be in view of the ground station.

I. Initial Configuration and System Setup

A software installation program will properly configure the software for the type of demodulator card, APT or WEFAX image reception, and printer configurations. Most vendors provide a software installation routine to assist the user with setting the correct interrupt levels and addresses unique to the personal computer and the specific type of computer operating system. Following installation of the demodulator card and software, an internal test routine may be run to validate proper installation of the hardware and configuration options.

One of the first items to customize in most direct readout software programs is to tell the program your geographic location and local time information. This data is used to help predict when the polar orbiting satellite will be in view of your station, and also to setup 24 hour scheduling of both APT and GOES imagery. Normally the program will ask for the following information:

Latitude Longitude Height above sea level

Time offset from Universal Time Coordinate (Greenwich) time

The latitude, longitude, and height above sea level can be obtained from a good quality atlas, local pilots, airports, or municipal government offices. The latitude and longitude values entered should be accurate to at least one arc minute or 0.0167 decimal degrees. Height should be accurate to the nearest 305 meters (1000 feet). UTC time offset is based on your local time zone. The UTC offset for Eastern Standard Time would be -5 hours, for Central Standard Time - 6 hours, etc. All four data points can usually be obtained by calling the local flight control center at the local airport. Alternatively, a GPS receiver may be used to directly input this data.

2. Satellite Image Capture and Scheduling

APT and WEFAX direct readout software needs to know which satellite will be transmitting the imagery so that it can be properly formatted and displayed, or to animate several frames of APT or WEFAX images. For systems that have built in receiver control, this will also set the correct frequency for the satellite transmissions. Most APT and WEFAX software uses the concept of a configuration file to define what is expected from specified satellites.

Several of the weather satellites differ in their characteristics. The Polar Orbiters use several different VHF frequencies to transmit the information, including 137.40 MHz, 137.50

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MHz, 137.62 MHz, 137.85 MHz, and 137.795 MHz. The image formats used by U.S. and Russian satellites are very different: U.S. satellites send two side-by-side images simultaneously, while the Russian satellites send one visible or infrared image only. U.S. satellite image information is synchronized (phase-locked) to the radio signal frequency, while most Russian satellites are not synchronized. When utilized, phase-locking allows the image registration control during reception, which assures that the image is precisely aligned vertically, without any sideways skew or bowing of the images. Finally, orbiters alternate between ascending passes (south to north movement) and descending passes (north to south movements). There are similar frequency and image display differences for the GOES and METEOSAT systems.

In order to properly receive and display orbiter images, the software must know which satellite will be transmitting the imagery. For example, if the desired polar orbiter is transmitting an image on 137.5 MHz, the receiver, being controlled by the software, will not receive the signal if it is tuned to 137.62 MHz. Furthermore, once the receiver is set to the correct frequency,

the image will not be displayed properly if the satellite type is set to Meteor when attempting to receive a U.S. NOAA satellite. Since the software has been set to satellite type of Meteor, the adapter card will listen for a 256 Hz tone burst that defines the image edge of a Meteor satellite, but the NOAA satellite sends an 832 Hz Tone burst instead. Since the expected tone burst will not be received, the image will not start

Thus, a configuration file will help determine which satellite profile needs to be implemented. A list is normally displayed of the various weather satellites capture modes, including: NOAA POES and GOES, Meteor, Feng Yun POES, METEOSAT, GMS and, possibly OKEAN/SICH.

Often the capture program will allow the user to specify the image sampling rate, which will define the image resolution. The APT and WEFAX images are sent as individual scan lines. Many direct readout adapter cards have the ability to vary the number of samples that are taken and store from each line of image information. When the sample rate matches the resolution of the images being transmitted, then the maximum image resolution is captured, and no increase in the image quality will be gained by setting the sample rate to a higher value. The cost for the increased resolution is that the stored file size increases with higher resolutions. An imaged capture at 4,800 samples per second will be 33 percent larger than one captured at 3,200 samples per second. So, the file size is a tradeoff for increased resolution.

The sampling rate also affects image symmetry. For example, the GOES and METEOSAT WEFAX images are transmitted in 800-by-800 pixel formats. Increasing the sample rate will increase the resolution of an individual scan line, but since the number of lines is fixed by its transmission format, the image will no longer maintain its original symmetry, and WEFAX weather maps will appear elongated. In a similar manner, optimally square pixels are obtained in NOAA APT image transmissions by using the 4096 Hz sample rate. Increasing or decreasing the sample rate will change the resolution at the expense of the image symmetry.

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The image capture routine will also allow setup up of a specific directory name to store the captured images, and the type of graphics file in which to store the image (i.e., GIF, JPEG, TIF, PCX, BMP, etc.).

The image capture routine also requires a method to correct for Doppler shift. Since the polar orbiters spend virtually all of their time moving from or toward the ground station receiver, this frequency as seen by the stationary receiver is shifted (the Doppler effect). If the receiver does not track and correct for the amount of shift, the image will bow as is shown in

Subcarrier~ Figure VII-2. This is due to the fact that Doppler shift slightly adds or subtracts to the 2400 Hz subcarrier being transmitted by the satellite, and the receiver does

Receiving Station

not track and compensate for this change. So, some type of hardware or software compensation must be provided. Use of a Phased Lock Loop (PLL) circuit in **satellite reception** the APT adapter card can correct the Doppler shift problem. Using a fixed reference oscillator, the Doppler changes shift the start and stop reference for each scan line. By setting the PLL clock, the hardware tracks the amount of Doppler shift and compensates for it. The use of the PLL forces true vertically aligned images in spite of the Doppler shift present on the satellite signal. (Note: All Russian

Meteor satellites prior to Meteor 3-5 did not use phase-locking of the image with the subcarrier, and thus the Meteor images will have some bowing in the image due to the Doppler effect).

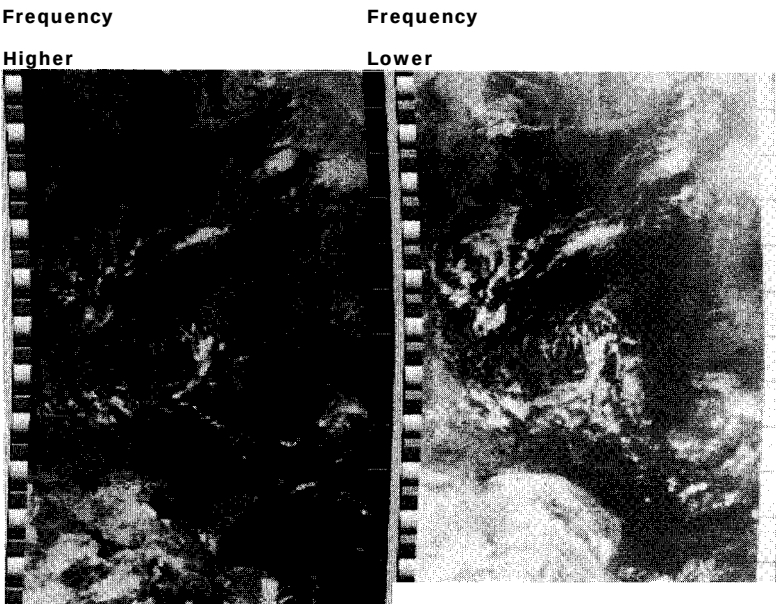


Figure VII-2. Doppler shift "bowing"

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DIAL S KHZ . i-&::: H:: !A4 MCAMP tiH

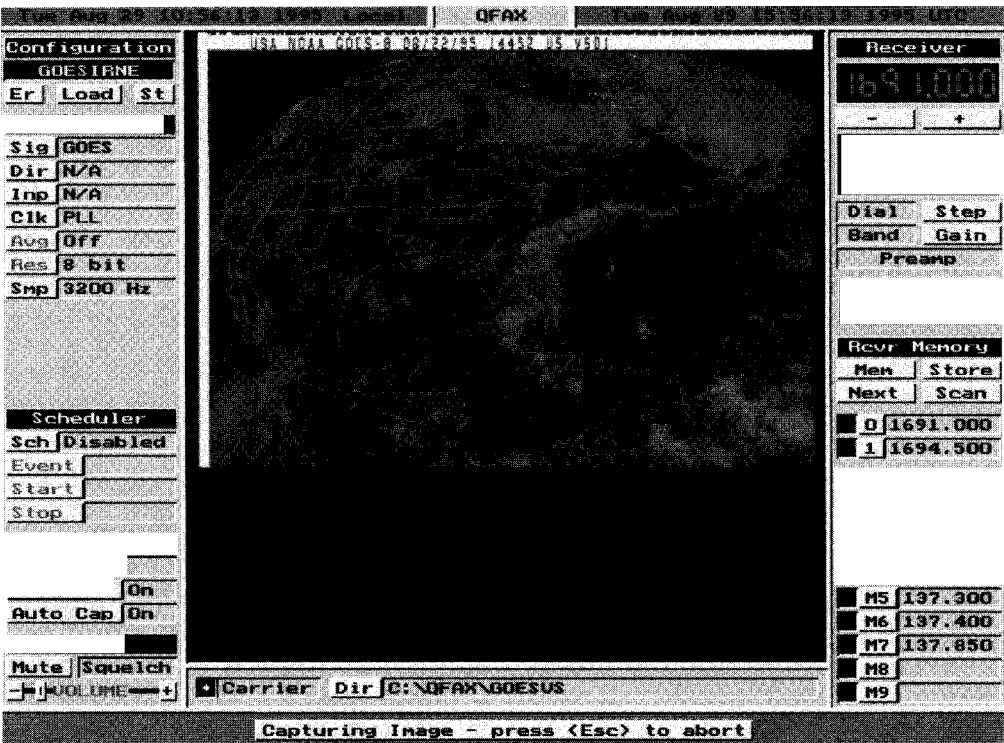


Figure VII-3. **WEFAX capture screen showing user-set parameters**

Figure VII-3 demonstrates the reception and capture of a visible light GOES-8 WEFAX image. Note the Configuration listing on the left of the frame showing the GOES satellite signal, sampling rate (Smp) of 3200 Hz, and the directory in which the image is being stored (C:\QFAX\GOESUS) in the lower center of the frame.

For images of the start/stop format (geostationary images) there are six sequences the software cycles through before capturing the image to disk or screen:

1. Waiting for the Start Tone
2. Start Tone Detected
3. Locking to Image Edge
4. Waiting for Image Start
5. Capturing Image
6. Waiting for Stop Tone

When the capture routine is selected in the software program, the software waits until a valid image start is detected. When a valid image start is detected, synchronization to the edge of the image will occur. After the software has locked to the image edge, it waits for the top of the image. Once the top of the image is reached, image data capture begins and the image will

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be painted on the screen one scan line at a time. A similar sequence is used for polar orbiter APT images, with the exception there are no start or stop tones in the APT transmissions.

The software program may also allow the user to establish time slots when images will be automatically received and stored to the hard drive. This allows unattended reception of images for later use or analysis at a more convenient time. Most scheduler routines work on a 24-hour format. The schedule will wait until the scheduled time before capturing the image for the scheduled duration. In the case of the GOES images, the capture may be determined by a time schedule or receipt of the Binary Coded Headers (BCH) sent by the GOES satellite. For the polar orbiters, normally you set each event in the scheduler start one minute before the image is transmitted and the stop time to one minute after transmission is predicted to end.

3. Satellite Prediction and Tracking

Several of the APT direct readout systems include a "Predict" function which provides satellite prediction, tracking, and APT data capture in a single, integrated program format. Use of the standard "SGP4" satellite orbital prediction model is common. This is a mathematical model intended to track and acquire data from polar orbiting satellites. The SGP4 prediction model is accurate for all low altitude satellites such as the NOAA POES and Russian Meteors. Although the program allows satellites to be entered which are not strictly covered by the SGP4 model, such as geosynchronous satellites, the accuracy of the predicted position is decreased since deep space perturbations are not accounted for. Further discussion on predicting when the satellite will be in view and orbital mechanics will be covered in the chapter on "Satellite Tracking and Prediction."

Three items are critical to the proper tracking of satellites during image capture:

Accurate time - Probably more critical than any other item, the PC clock should be accurate to the nearest second or better. There are shareware programs available from on-line bulletin boards and the Internet that allow the modem to dial the National Bureau of Standards and use the data provide to set the PC clock to an accuracy of 0.5 seconds or better. Alternatively, a GPS receiver may be used to set the PC clock.

Accurate Ephemeris - The ephemeris data need to be updated at least every two weeks. This is actually radar observation data gathered by the U.S. Air Force and is the information used by the satellite prediction program (SGP4 model) to determine when a satellite will be in view of the ground station. Ephemeris data (otherwise known as Keplerian elements) may be obtained from many bulletin boards and the Internet. Some sources are in the Appendices.

Accurate Ground Station Location Information - the latitude, longitude, and height above sea level entered during the initial setup of the APT program will be used by the satellite prediction routines in determining acquisition of signal and loss of signal times for the satellites.

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Figure VII-4 shows a prediction program integrated with the APT capture routine. Note the map of the U.S. on the left side of the image, showing the ground track of a NOAA-14 pass. At the bottom left side of the screen, under the Zoom Map, the current satellite location data is displayed in a format identical to that displayed in the tabular display window. On the right side of the screen are the actual visible and infrared APT images from this pass of NOAA-14.

Alternatively, a separate satellite prediction/tracking program may be used for those APT systems that do not include an integrated satellite prediction function. Use of a multitasking operating system such as Windows 95 would allow both the APT capture program and satellite tracking routine to be run concurrently. Such programs are available as "shareware" and "freeware."

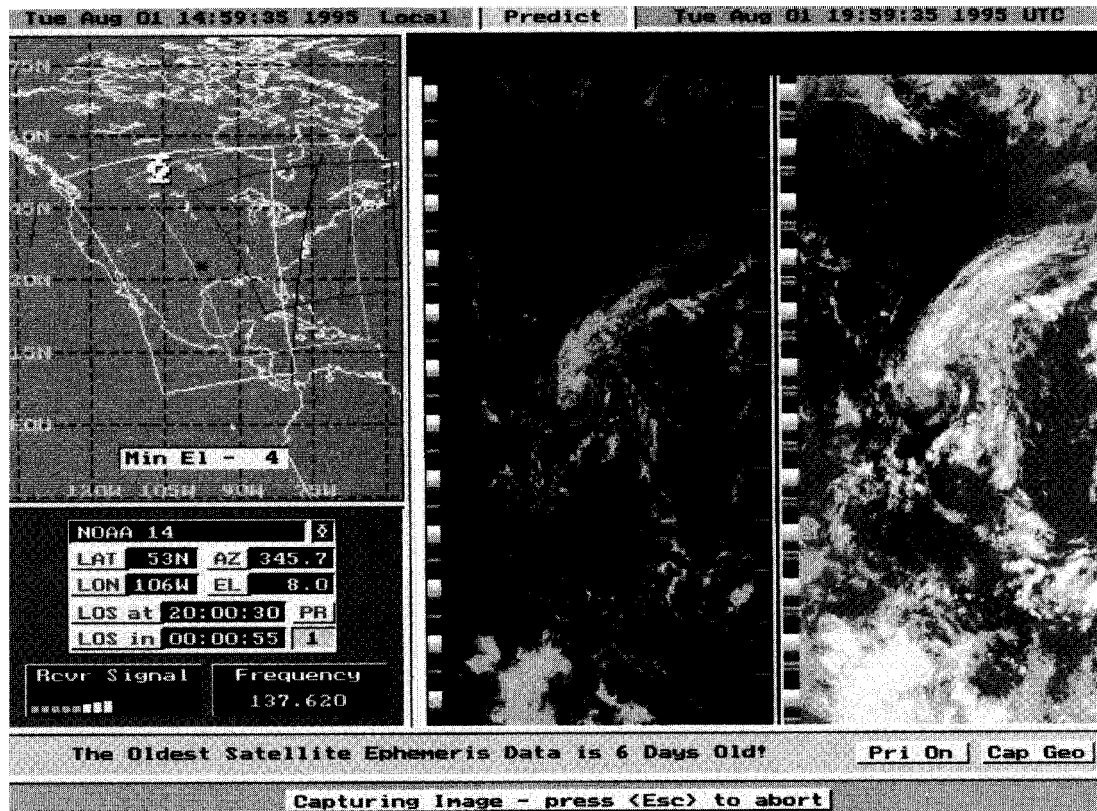


Figure VII-4. Track prediction and satellite sub-point location screen for a NOAA-14 pass

4. Viewing and Enhancement of Satellite Imagery

The ultimate goal of direct readout is the actual viewing and manipulation of the satellite imagery. APT and WEFAX programs often provide extensive image processing functions such as zoom, rotate, contrast, brightness, false coloring, sharpen, smooth, noise filter equalize, the NOAA enhancement curves, and even 3-D effects of the IR imagery are possible. The ability to

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place map gridding lines (longitude/latitude and geopolitical boundaries) and a temperature calibration of the NOAA imagery are other features often integrated into the programs and can add to the information value extracted from the image. Once image enhancement has been performed on the original image, the new image may be saved under a different filename to compare and contrast with the original data.

Figure VII-5 is an example of the Zoom outline box around Hurricane Erin in the visible NOAA imagery. The user may select any portion of the image to zoom, and the outlined box will then be zoomed by the zoom factor as shown in the pull down box in the left side of the image. Note the unusual capture of the Moon in the upper right-hand quadrant of this GOES infrared image

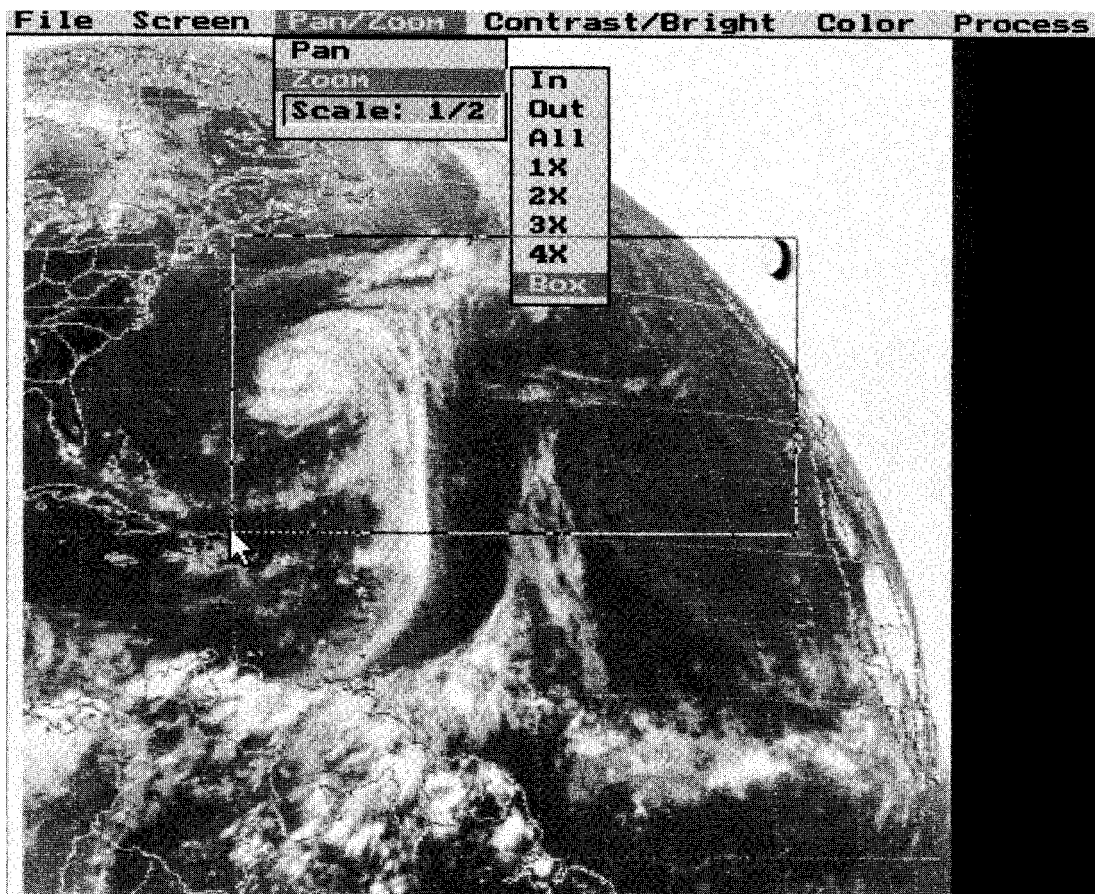


Figure VII-5. GOES WEFAX capture screen showing image "zoom" capability

One very interesting manipulation of the satellite imagery is the use of the NOAA Enhancement curves. When temperature differences in transmitted infrared images are small, it becomes difficult for the human eye to recognize significant cloud and surface features present

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in the images. The information may be present, but the observer cannot discern the features. Such phenomena include convective weather features, haze, fog, ocean current boundaries, and terrain features. Image enhancement through the use of the built-in NOAA curves increase the contrast between targeted features and the backgrounds, which serves to make the features more apparent. The provided curves also serve as a convenient way to identify several different types of features within the images. The images may also be colorized, by changing the palettes used for the image. Such false-coloring can often assist with accentuating cloud tops, rotation in hurricanes, and sea surface temperatures.

Table VII-1 lists some of the NOAA enhancement curves included in the software are:

NOAA Curve Designation

Image Use

Ab Bb Cb DB Eb Fb Hb Mb Pb Sa Za Lin

Hurricane Curve

Hurricane Pattern Recognition Cold Cloud Tops

Convective Activity

Middle Clouds & Convection Hydrology Curve

Lower Clouds

All Season Clouds

Pacific Coastal Upwelling Sea Surface Temperature Lower & Upper Level Clouds Reset to

Linear Gray scale

Table VII-1. NOAA Infrared Enhancement Curves and Their Application Use

Figure VII-6 displays a NOAA curve submenu, the accompanying histogram, and simple image enhancement with the NOAA *Hurricane* (Ab) curve.

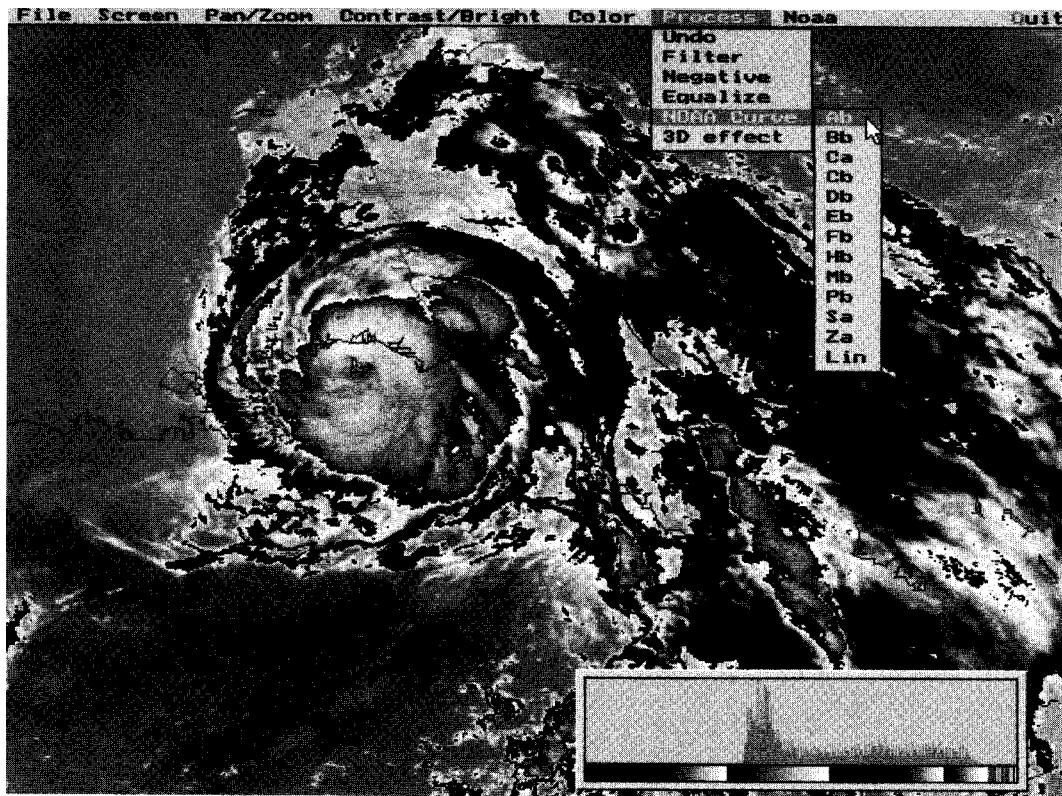


Figure VII-6. APT infrared channel enhanced image using the NOAA Ab Hurricane curve

The map overlay function is another useful feature of direct readout programs. The polar orbiting weather satellites do not transmit images with map overlays such as is done on the GOES WEFAX direct readout. The lack of map overlays can create difficulties identifying land and water features in images covered with clouds, since no reference point can be found in the image. APT software often overcomes this limitation with the ability to create map overlays (longitude, latitude, and geopolitical boundaries) for NOAA polar orbiting weather satellites.

Figure VII-7 shows a completed navigation map overlay for a NOAA-14 pass over the United States. Moving the cursor around the image will bring up the cursor reference points indicating the latitude and longitude of the current cursor location, as well as the bearing and distance from the home ground station location.

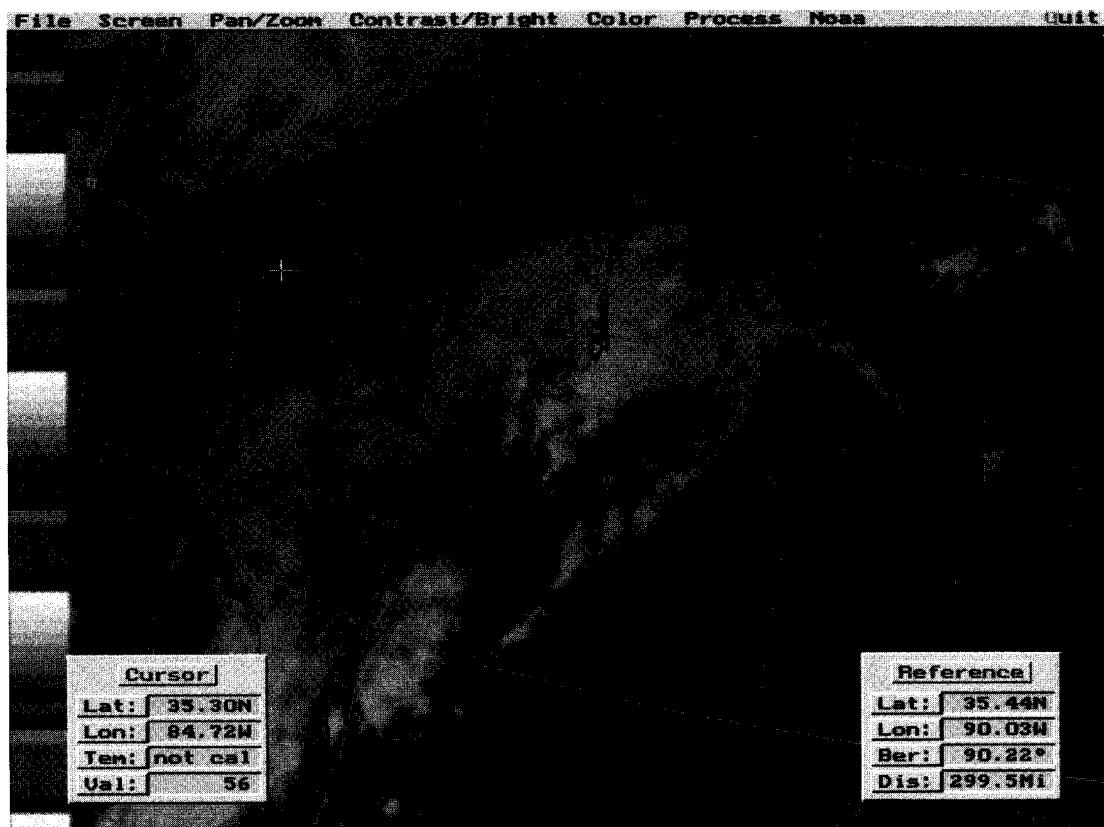


Figure VII-7. APT visible channel image with software applied latitude/longitude, geographical boundaries and cursor location

5. Image Animation

The image animation function is used to display a sequence of captured images. Individual frames of images are usually stored in a special subdirectory based on a specified capture schedule. The number of frames to be animated and speed of the animation sequence is entered in the program, and the imagery is put into a loop on the computer screen. Some programs can be configured to delete the oldest image and add in the newest image for a continuous animation of the current weather. The animation capability is very useful for tracking hurricanes, weather fronts, and even changes in sea surface temperatures and can help in understanding to the physical processes taking place.

Shareware Direct Readout Software

Over the past several years direct readout enthusiasts have written their own image capture and display software, and designed some very simple demodulator circuits that can be built by the electronics hobbyist for less than \$50. The software has been freely distributed as "shareware," and these programs can be downloaded from bulletin boards and the Internet.

One of the more popular programs is JVFAX, written by Eberhard Backeshoff, amateur radio operator DK8JV. JVFAX is a multifunction image-communications package that allows operations of APT direct readout, amateur radio slow scan television, and radio facsimile modes. It requires an IBM PC or compatible, 386 processor or better, and a video display card capable of

at least 640 pixels by 480 lines by 256 shades of gray scale. JVFX was written in IBM DOS format, and will not run under Windows at the present time.

JVFX software comes as a "self-extracting" file that expands into all the files required to operate the program. Schematic diagrams for a simple demodulator circuit and associated documentation are included. The installation process is very simple. The current version of JVFX is JVFX71.

JVFX includes a simple to use SETUP program just like commercial software. A menu lets you type the options that apply to your system. JVFX can receive and store imagery from the polar orbiting and geostationary satellites, including the European METEOSAT program. Image enhancement and animation routines are also provided. Printed Circuit boards and associated components can also be purchased to build the demodulator card.

Another popular shareware program to receive APT imagery is called SBDSP. This program name stands for SoundBlaster Digital Signal Processing. SBDSP was written by Mark Sims of the Dallas Remote Imaging Group (DRIG) and utilizes the 8 and 16 bit SoundBlaster cards found in many of today's personal computers. The software properly formats and displays polar orbiting APT transmissions by inputting the audio from the APT receiver to the SoundBlaster adapter card. The resulting audio file is processed by the software and displayed on the PC video monitor as an APT image. Both the JVFX and SBDSP software may be downloaded at no charge from the DRIG Internet site at: <ftp.drigrig.com> /pub.

VIII. ADVANCED DIRECT READOUT SYSTEMS

The popularity of APT and WEFAX direct readout systems have grown over the years due to the ability of the user segment to receive both real-time (NOAA POES) and near-real time (GOES) weather satellite imagery on a daily basis with low cost and easy to maintain receiving equipment, and not be charged for either the service or the data products. The more advanced direct readout systems (HRPT and GVAR) had, until recently, been both very expensive to procure and complicated to operate. The cost of an HRPT ground station could easily exceed \$250,000 with similar costs for the GOES VAS systems.

In the late 1980's amateur radio operators and APT imaging enthusiasts were experimenting with HRPT receiving systems of their own design. Amateur radio operators have always been at the forefront of designing and building their own systems, and advanced direct readout imaging stations were no exception. Thanks to the efforts of experimenters such as Dr. John DuBois and Ed Murashie, basic schematics and components for HRPT ground stations were available in kit form by 1990, and several amateur weather satellite enthusiasts finally had access to the high resolution imagery from NOAA POES. Similar "amateur" development occurred for the earlier GOES VAS data products (and later GOES GVAR). These advanced direct readout systems were based on IBM personal computer technologies, and utilized the high resolution graphics capabilities and fast microprocessors necessary to receive, display, and store digital imagery.

Inevitably, these amateur designs were expanded and enhanced by several commercial manufacturers, and HRPT, VAS, and GVAR advanced ground stations may now be either purchased commercially or assembled from component parts with costs ranging from \$5,000 to \$20,000. Although these prices still represent a significant expenditure, they are an order of magnitude less cost than the \$100,000 to \$250,000 commercial systems available just a few years ago. Since some of the ground station components of an APT/WEFAX system may be

utilized for HRPT and GVAR (personal computer, disk storage, tracking antennas), it is actually possible to configure an HRPT station for approximately \$5,000 and a GVAR station for about \$10,000.

This chapter will review the basic components of HRPT and GVAR direct readout stations, and discuss the advanced capabilities of the high resolution imaging systems.

POES High Resolution Picture Transmission Direct Readout

By way of review, the AVHRR instrument is the primary imaging system flown on the NOAA series of satellites. This instrument provides the raw data for the High Resolution Picture Transmission (HRPT) and Automatic Picture Transmission (APT), Global Area Coverage (GAC), and Local Area Coverage (LAC) modes of operation. The LAC and GAC services use onboard tape recorders to store the digital information for selected portions of the satellite's orbit. This recorded data is transmitted to ground stations in the United States for processing, and re-broadcast via other services around the world. Most direct readout users would not be able to receive and process these recorded transmissions

The AVHRR instrument has a resolution of 1.1 [km. in](#) 10 bit data in five separate spectral bands. Table III-5 summarized the spectral range and primary uses of the five sensors. Contrasted with the 4 km, 8 bit data and 2 spectral bands for the APT transmissions, HRPT, with its 5 data channels and 10 bits of data represents about a 20-fold advantage in the amount of information that may be analyzed when compared to APT data. This is very important to meteorologists and other professionals who need the most accurate information available for analysis.

Table VIII-1 reviews the parameters for the AVHRR HRPT digital transmissions from the NOAA POES satellites.

Transmit Frequencies	Antenna Polarization	RF Carrier	Modulation	Bandwidth
Lines per Frame	Number of Digital Words	Word Rate		
Number of bits	Words per image	Spectral channels		
1698,1707,1702.5 MHz	Right-hand Circular	Digital, Split Phase,	Phase Modulated	3 MHz
6 per second (360 lines per minute)	11090 per line			
66,540 per second (665.4 kbps)	665,400 per second			
2048 per line	5			
Channel 1 0.58-0.68 μ M	Channel 2 0.72-1.1 μ M	Channel 3 3.55-3.93 μ M		
Channel 4 10.3-11.3 μ M	Channel 5 11.5-12.5 μ M			

Table VIII-1. Characteristics of the HRPT Digital transmissions

The question arises as to what additional ground station equipment is required to receive and display HRPT images. Although the basic requirements appear similar to those required for APT ground stations, the high data rate and digital nature of the transmissions require some specialized circuitry. A basic HRPT ground station would consist of the following elements:

1. 2. 3. 4. 5. 6. 7. 8. 9. 10.

Four-foot (or larger) parabolic dish

Antenna positioner and control hardware including azimuth and elevation rotators Feedhorn and quadrature combiner

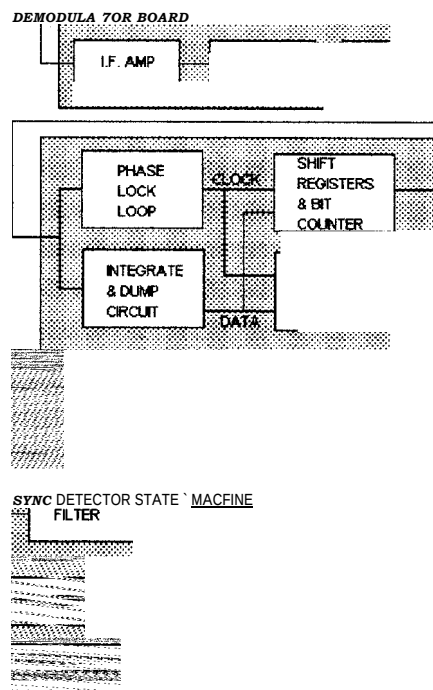
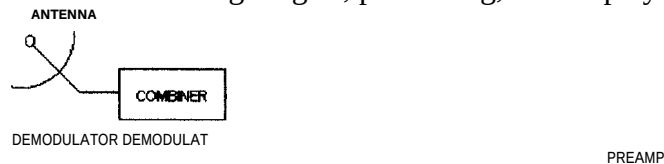
Low noise amplifier Wide band receiver

Down converter circuitry Phase-locked loop

demodulator Bit-synchronization board

Personal Computer

Software for image ingest, processing, and display



The basic system described by Dr. DuBois in 1990 has served as the basis for a number of commercial systems being sold today. Although some of the components have been combined into integrated units for ease of manufacture and assembly, today's commercial systems all utilize the same essential building blocks.

Basic HRPT Station Design

SYNCHRONIZER BOARD

Antenna - The HRPT signal is

Figure VHI-1. A block diagram of a basic HRPT ground station transmitted at 1698 and 1707

station based on the design work of John DuBois MHz, with backup at 1702.5 MHz. At these frequencies the beamwidth is very narrow and proper tracking of the satellite is essential. Most HRPT systems employ a parabolic dish. Experience has shown that a four-foot dish (1.2 meters) provides adequate gain (around 24 dB) while still providing a manageable platform for tracking. Some experimenters have utilized a six-foot "loop yagi" antenna design, but stability of the antenna during tracking can lead to signal fades and loss of signal

synchronization and lock. Parabolic dishes are available commercially at moderate cost. From a durability, accuracy, and maintenance perspective, they are a very good investment.

8-3

Feedhorn and Combiner - The feedhorn can be around 17 cm. long and 12 [cm. in](#) diameter, centered at the focus of the parabolic dish. Two quarter-wave monopole probes, each about 4 cm. long, need to be placed 90 degrees apart about 4.5 cm. from the back of the feedhorn. Circular polarization may be obtained by feeding one pole 90 degrees out of phase with respect to the other. This is the quadrature combiner.

Low-Noise Preamplifier - A low noise preamplifier is a must for good quality HRPT images. The LNA noise figure should be 0.8 dB or lower. This corresponds to a noise temperature of 59 degrees Kelvin. The gain should be at least 30 dB.

Down converter - The HRPT signal at 1698 to 1707 MHz is often converted to a more transportable signal in the VHF frequency range. This is the same method utilized for WEFAX systems at 1691 MHz. A down converter circuit is used to perform this conversion. Frequencies of 128 to 145 MHz are often used as the output of the down converter. Good quality down converters used 6 pole filters to prevent out of band interference to the HRPT receiving system.

Demodulation - The demodulation section is essentially an amplifier-filter that raises the signal level and establishes the final system band pass for the phase demodulation. A phased-lock loop (PLL) demodulator circuit is used.

Bit and Frame Synchronization - A bit synchronizer is required to extract the data clock rate and some means of decommutating the telemetry and different wavelengths of the AVHRR image. Frame synchronization is accomplished with another circuit to complete the telemetry and image formatting.

Personal Computer - The personal computer needs to have enough power to handle the 665 kbps data rate and substantial storage for the hundreds of megabytes of AVHRR data. Today's 80486, Pentium and similar processor computers are more than sufficient for this purpose. Minimum disk storage should be two gigabytes and 16 megabytes of RAM would be a standard configuration. The same computer used for APT/WEFAX reception may be utilized for HRPT if there is enough disk storage and slots for the HRPT circuitry.

GOES GVAR High Resolution Direct Readout

The NOAA GOES I-M series of satellites have two primary instruments, the Imager and Sounder. The Imager is the instrument most people are familiar with, as it produces the views from space we most often see. The Imager is a five-channel imaging radiometer that can sense reflected and radiant energy. Table VIII-2 summarizes the characteristics of the 5 channels that comprise the Imager data.

8-4

Channel	Wavelength Range m	Resolution at nadir	Meteorological use
1	0.55-0.75	1 km	Visible cloud cover

2	3.80-4.00	4 km	IR nighttime cloud cover
3	6.50-7.00	8 km	Water vapor detection
4	10.20 - 11.20	4 km	Surface temperature, clouds
5	11.50 -12.50	4 km	Sea surface temperature, <u>water vapor</u>

Table VIII-2. GOES I-M Imager Sensor Summary

The GOES high resolution direct readout transmission is a bit different than the POES HRPT transmission. On the POES spacecraft, what is sensed by the AVHRR instrument is processed on board the spacecraft and then transmitted directly to the direct readout user on the ground as the spacecraft flies overhead. With the GOES spacecraft, the 5 channel, 10-bit Imager raw data is downlinked to the NOAA CDA station at Wallops Island, Virginia at a rate of 2.62 Mbs. Here it is processed and formatted into the GVAR format, then sent back up to the GOES satellite at a rate of 2.111 Mbs to a relay transmitter. This relay transmitter provides the GOES GVAR transmission service (called the processed data relay or PDR) that is received by users. The GVAR data stream contains the data from both the Imager and Sounder instruments as well as calibration and spacecraft navigation data, spacecraft telemetry and miscellaneous products.

In Table VIII-3 is an overview of the characteristics of the GVAR data transmission from the U.S. GOES satellites.

Transmit Frequency Antenna Polarization RF Carrier Modulation Bandwidth
Lines per Scan

Number of Digital Words Words per image Number of bits
Spectral channels
1685.70 MHz Linear
Digital, Biphase, Shift Keyed (BPSK) 6 MHz
8 Variable Variable 2,111,360 per second 5

Table VIII-3. Characteristics of the GVAR digital transmissions

8-5

It should be noted that the number of words making a complete line (or E-W swath), or a complete GOES image is variable. How the Imager instrument aboard the GOES operates to make an image is substantially different from the AVHRR operation aboard the POES. The AVHRR scans continuously using a mirror rotating at a constant 360 rpm. An image is essentially unlimited along the direction along the satellite track over the Earth's surface and is constrained by a fixed, consistent amount in a cross-track direction. With GOES, the Imager scanning mirror can be moved in an East-West direction and North-South direction by variable amounts depending on how large or small an area of the viewable Earth is desired to be imaged. This results in a variable number of Imager data words being transmitted, followed by a variable

number of Sounder data words (depending on how many are available for transmission) which comprise the total GVAR data structure.

Basic GVAR Station Design

In the simplest form, the basic components of a GVAR station are very similar to an HRPT receiving station. The data stream is captured using a parabolic antenna, collected at a feedhorn, passed through a preamplifier and down converted, demodulated, after which bit and frame synchronization occurs. However, the exact specifications of each component are different to accommodate the different transmission frequencies, bandwidth, data rates, etc.

Antenna - The GVAR transmission is also in the S-band, at 1685.7 MHZ. Parabolic dishes are required, as with HRPT, with a minimum 3 m (10-foot) diameter required for acceptable results, and a somewhat larger size of 3.6 m (12-foot) diameter preferred. However, once the antenna is aimed at a geostationary satellite, it can be locked in position and does not have to be steered as is the case with HRPT.

Feedhorn - The feedhorn assembly is not quite as complex, as the polarization of the signal is not changing with respect to the ground station as the satellite moves as is the case with HRPT. The feedhorn is aligned once to maximize the linearly polarized signal from the GOES transmitter and then fixed in place.

Low Noise Preamplifier - A preamplifier for a GVAR receiving system is essentially the same as would be used in an HRPT system.

Down converter - The GVAR signal transmitted at 1685.7 MHZ is converted to a signal in the VHF frequency range. The converted output signal is usually at or about 70 MHZ and fully filtered to prevent out of band interference.

HRPT.

Demodulation - The demodulation technique is nearly the same in both GVAR and

Bit and Frame Synchronization - While there are different bit frame patterns in GVAR and HRPT, the technique for frame processing is nearly the same.

8-6

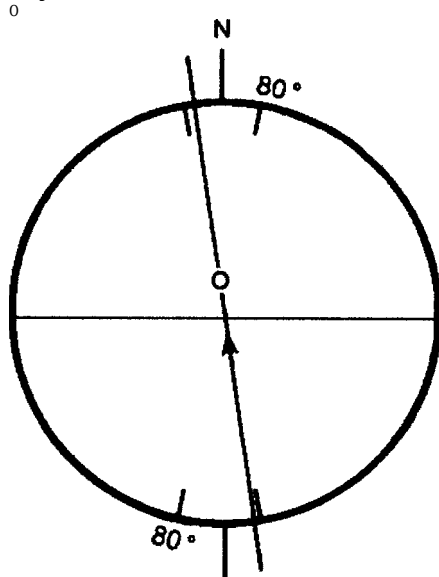
Personal Computer - Because 5 channels of HRPT data are received only for a short period of time (the length of a pass over the station), while GVAR is available nearly continuously, the disk storage and random access memory requirements for GVAR are greater. A full disk scan of GVAR data requires approximately 350 megabytes of storage. Also, because of the larger file sizes typical with GVAR images, animation of imagery usually requires 32 MB (or greater) of RAM.

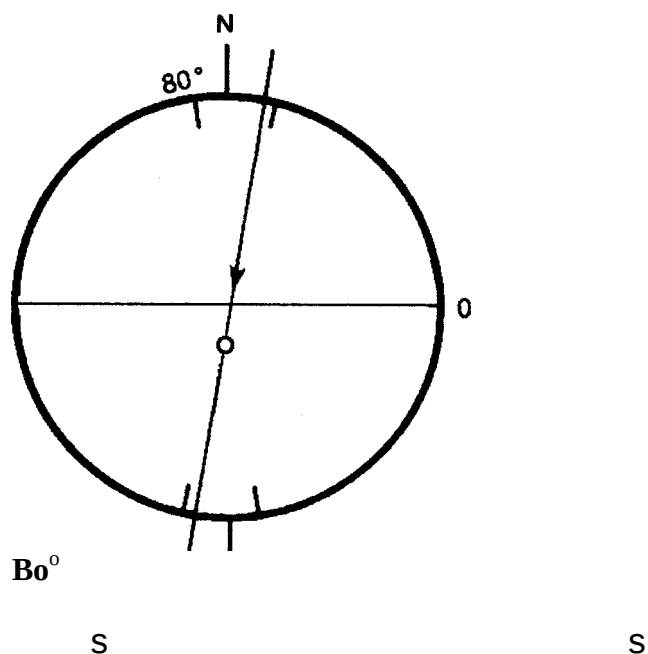
In spite of the somewhat greater hardware requirements for a GVAR ground receiving station, the advantage of GVAR over HRPT is the 24-hour availability of the data. HRPT is only available at certain times of the day when a polar orbiting satellite is within view of the receiving station. Each user has to balance the costs involved, the type of data needed, and application of the data when choosing whether HRPT or GVAR would be more appropriate.

IX. SATELLITE PREDICTION AND TRACKING

In order to obtain high quality APT video using direct reception, accurate information concerning locations, movements and times that the satellites can be received must be available. This is necessary because signal reception is possible only while the satellites are above that ground station horizon. Although all polar orbiting satellites have basic orbital characteristics in common, each spacecraft is unique in its orbital parameters and needs to be tracked individually. The data necessary to locate and track the meteorological satellites is generally not difficult to obtain and sources of this information are provided in this section and the Appendices. The generation of future orbits of a given satellite can be easily calculated and, if a directional antenna is used, determining the azimuth and elevation of the satellite as it passes over the ground station is not difficult after the basic orbital patterns are understood.

Figure IX- I shows a typical orbital path of a NOAA-TIROS series satellite. A polar orbit, in strict terms, would carry the satellite directly over the north and south poles with an inclination of 90 degrees to the equator. Both the TIROS series and Russian Meteor series satellites have orbits that pass within 10 degrees of the geographic poles and have slight inclinations relative to the equator. The advantage of a polar orbit is that the satellite will have the best routine coverage for all areas of the Earth's surface during a 24-hour time frame. In addition, all of the TIROS series satellites are inserted into sun-synchronous orbits which will place the spacecraft in a relatively constant relationship to the sun so that the ascending node (northbound equator crossing) will remain at a constant solar time. This permits images and other meteorological data to be received by direct broadcast at about the same local time each day.





Ascending Node
0

Descending Node

Figure IX-1: A typical orbital path of a TIROS-N series satellite

The time required to complete one orbit is referred to as the NODAL PERIOD of that satellite. For polar orbiting satellites this is measured from the time it crosses the equator (0 degrees latitude) moving northward (ASCENDING NODE) until the next northbound equator crossing. The Southbound equator crossing is called the DESCENDING NODE of that orbit. During the time of one orbit (NODAL PERIOD) the Earth is rotating at 0.25 degrees per minute. This causes the next equator crossing to be farther west than the previous one. The amount of Earth rotation between two successive equator crossings, given in degrees of longitude at the equator, is known as the satellite INCREMENT. This increment can be calculated as follows:

$$\text{INCREMENT} = \text{NODAL PERIOD (in minutes)} \times 0.25 \text{ degrees}$$

If a satellite's PERIOD, INCREMENT, and the time and longitude of an equator crossing are known, it is not difficult to predict future orbits for that satellite for days or months in advance. This can be done by simply adding increments and the times of orbits to get the next longitude of an equator crossing and the time this will occur. This is, however, a timeconsuming task if each orbit is calculated and recorded by hand. A more convenient approach is to use a computer and a simple orbit prediction program to do these calculations. Any user with some knowledge of computer programming can develop and run programs for a variety of computers that will accurately predict future orbits of any polar orbiting satellite. These programs can take various approaches from simple listings of equator crossing longitudes and times to more complex programs that give local station times, orbital numbers, antenna tracking data for azimuth and elevation and a variety of other information.

Table IX- I lists an example Basic computer program that will calculate the future equator crossings for polar orbiting satellites if accurate data are available for one reference orbit. The following reference orbit input data are required to operate this program:

1. Month of the equator crossing of the reference orbit

2. Day of the equator crossing of the reference orbit
3. The hour of the equator crossing of the reference orbit
4. The minute and decimal minute of the equator crossing
5. Longitude of the north bound equator crossing (Ascending Node)
6. The Orbital Increment of the satellite
7. The time, in minutes, of the orbital period (Nodal Period) of the satellite

These data are available from a number of sources, some of which are listed in the Appendices. The computed equator crossing locations and times provided by this program, when used in conjunction with a tracking map shown in this publication, are all the information needed to accurately determine when a polar orbiting satellite will pass within reception range of a given ground station.

9-2

```

10  CLEAR : TEXT : HOME
20  PRINT "POLAR ORBITING SATELLITE PREDICT"
30  PRINT "NUMBER OF MONTH?"
40  INPUT M
50  PRINT "DAY OF REFERENCE CROSSING?"
60  INPUT D
70  PRINT "LONG. OF ASCENDING NODE (DEGREES)"
80  INPUT E
90  PRINT "HOUR OF REFERENCE CROSSING? (USE 24 HOUR CLOCK)"
100 INPUT T
110 PRINT "MINUTE AND DECIMAL OF REFERENCE CROSSING?"
120 INPUT X
130 PRINT "ORBITAL INCREMENT BETWEEN ORBITS?"
140 INPUT W
150 PRINT "NODAL (ORBITAL) PERIOD? NOTE: ENTER ONLY MINUTES IN EXCESS OF 60."
160 INPUT F
170 PRINT "SATELLITE NAME AND FREQUENCY?"
180 INPUT A$
190 PRINT A$
200 PRINT
210 PRINT "DATE TIME LONGITUDE"
220 PRINT
230 PRINT
240 REM
250 H = 1:1 = W
260 LET Y = F
270 LET 2 = Q + 1
280 LET B = E + 1
290 IF B >= 360 THEN B = 13 - 360
300 LET S = T + H
310 LET R = X + Y
320 IF R >= 60 THEN 340
330 IF R <= 60 THEN 360
340 LET S = S + 1
350 LET R = R - 60
360 IF S > 24 THEN 370
370 GOSUB 480
380 R = INT (R * 1000 + .5) / 1000
390 B = INT (B * 1000 + .5) / 1000
391 HTAB 15
392 PRINT S;
393 PRINT " ";
394 PRINT R;
395 HTAB 33
396 PRINT B
410 LET T = S
420 LET X = R
430 LET E = B
440 LET Q = Z
450 IF D <= 28 THEN 240
460 IF D >= 30 THEN 470
470 IF D >= 28 THEN 520
480 IF S >= 24 THEN D = D + 1
490 IF S >= 24 THEN PRINT : PRINT M "P'D: PRINT A$"
500 IF S >= 24 THEN S = S - 24
510 RETURN
520 IF M = 1 THEN 640
530 IF M = 2 THEN 690
540 IF M = 3 THEN 640
550 IF M = 4 THEN 720
560 IF M = 5 THEN 640
570 IF M = 6 THEN 720
580 IF M = 7 THEN 640
590 IF M = 8 THEN 640
600 IF M = 9 THEN 720
610 IF M = 10 THEN 640
620 IF M = 11 THEN 720
630 IF M = 12 THEN 640
640 IF D <= 31 THEN 240
650 IF D = 31 THEN 660
660 D = 1
670 M = M + 1
680 IF M = 13 THEN M = M - 12
690 M = M + 1
700 D = 1
710 COTO 760
720 IF D <= 30 THEN 240
730 IF D = 30 THEN 740
740 D = 1
750 M = M + 1
760 END

```

Table IX-1. A Basic computer program for simple orbit prediction

Table IX-2 is a short example of the printout of Equator crossing times and longitude using the Basic program in Table IX-1 and the required 7 data inputs for NOAA-10. Table IX-3 contains the location in degrees of longitude and latitude of a typical NOAA-TIROS series polar orbiting satellite (NOAA-10) for every two minutes during one orbit. These locations are known as the suborbital points. These points change during each orbit, but the orbital track traced over the Earth's surface does not appreciably change during any orbit of these satellites. If these points are plotted on a polar projection map, they form a track as shown in Figure IX-2. If this track is copied on a transparent film and placed on the polar map shown in Figure IX-3 so that this sheet can be rotated about the north pole (X on Figure IX-2), a simple but effective satellite tracking system is formed. By placing the arrow at any ASCENDING equator crossing longitude, the path that the satellite will follow across the northern hemisphere during that orbit can clearly be seen. Each two minute mark on Figure IX-2 represents two minutes of travel *after the time of the equator crossing*. Of course, PC based tracking programs are more convenient, but his exercise does give one an appreciation of the methodology.

POLAR ORBITTING SATELLITE PREDICT	5/2	
NUMBER OF MONTH?	NOAA-10 137.50	
?5	0:33.076	73.91
DAY OF REFERENCE CROSSING?	2:14.361	99.23
?1	3:55.646	124.55
LONG. OF ASCENDING NODE (DEGREES)	5:36.931	149.87
?79.43	7:18.216	149.87
HOUR OF REFERENCE CROSSING? (USE 24 HOUR CLOCK)	7:18.216	175.19
	8:59.502	200.51
MINUTE AND DECIMAL OF REFERENCE CROSSING?	10:40.788	225.83
?55.08	12:22.074	251.15
ORBITAL INCREMENT BETWEEN ORBITS?	14:3.359	276.47
?25.32	15:44.644	301.79
NODAL (ORBITAL) PERIOD? NOTE: ENTER ONLY MINUTES IN EXCESS OF 60.	17:25.929	327.11
?41.2855	19:7.214	327.11
SATELLITE NAME AND FREQUENCY?	19:7.214	352.43
?NOAH-10 137.50	20:48.499	352.43
NOAA-10 137.50	20:48.499	17.75
	22:29.785	43.07
	5/3	
	NOAA-10 137.50	
DATE TIME LONGITUDE	0:11.07	68.39
	1:52.356	93.71
2:36.366 104.75	3:33.642	119.03
4:17.651 130.07	5:14.928	144.35
5:58.937 155.39	6:56.214	169.67
7:40.223 180.71	8:37.5	194.99
9:21.509 206.03	10:18.785	220.31
11:2.794 231.35	12:0	245.63
12:44.079 256.67	13:41.355	270.95
14:25.364 281.99	15:22.641	296.27
16:6.649 307.31	17:3.926	321.59
17:47.935 332.63	18:45.211	346.91
19:29.22 357.95	20:26.496	12.23
21:10.505 23.27	22:7.781	37.55
22:51.79 48.59	23:49.067	62.87

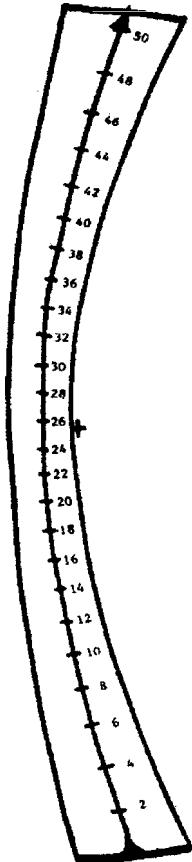
Table IX-2. Calculated equator crossing times and longitudes for a NOAA satellite

9-4

TIME	(In Minutes)\Satellite	Location in Degrees
0	4.4 South	39.9 East
2	2.7 North	38.4 E

4	9.7 N	36.8 E
6	16.8 N	35.2 E
8	23.8 N	33.4 E
10	30.8 N	31.6 E
12	37.8N	29.5E
14	44.8 N	27.1 E
16	51.7 N	24.2 E
18	58.6N	20.4E
20	65.3 N	15.0 E
22	71.7 N	6.4 E
24	77.5 N	10.0 West
26	81.2 N	44.3 W
28	80.0 N	88.6 W
30	75.1 N	113.5 W
34	62.3 N	132.4 W
36	55.5 N	137.0 W
38	48.6 N	140.3 W
40	41.6 N	143.0 W
42	34.6 N	145.2 W
44	27.5 N	147.2 W
46	20.5 N	149.0 W
48	13.4 N	150.7 W
50	6.3 N	152.3 W
52	0.8 South	153.8 W

Table IX-3. Latitude and longitude of a NOAA satellite subpoint, at two-minute intervals



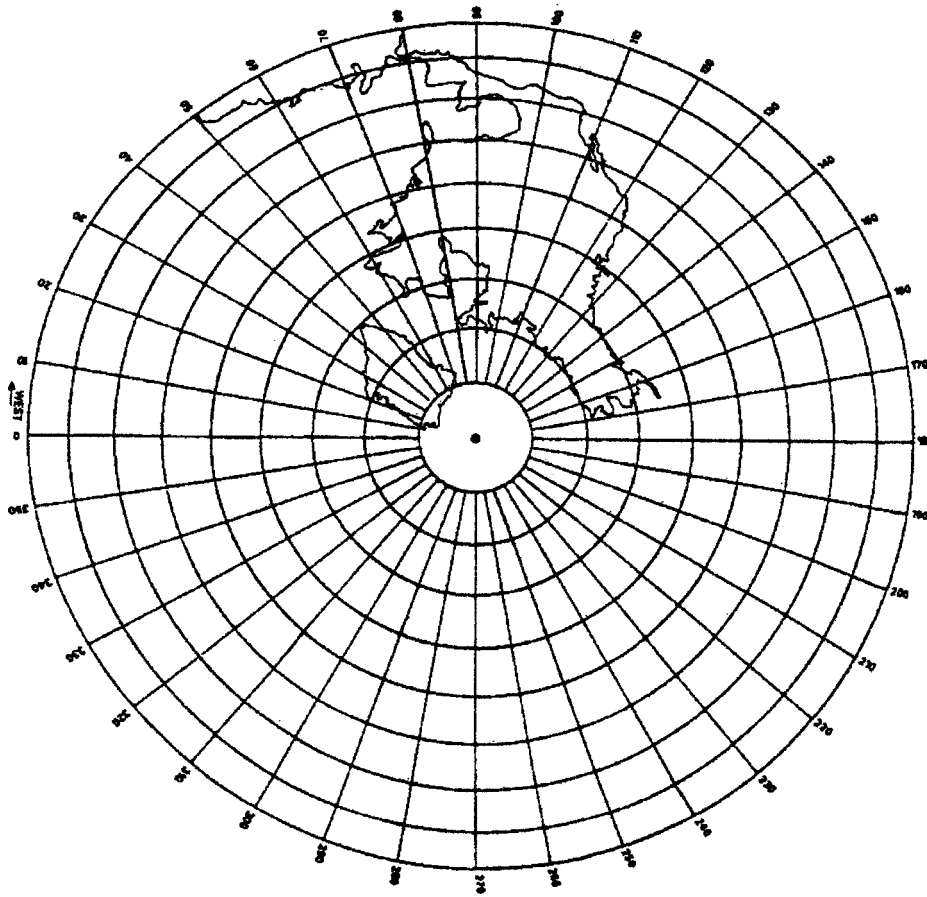


Figure IX-2. Typical TIROS-N orbital track plotted at 2-minute intervals

3. Northern hemisphere orbital track plotting map

Reception of the 137-138 MHz APT signal from the satellites is essentially "line of sight" which means that the satellite must move above the ground station horizon before APT images can be received. This is a function of the altitude of the orbit. Since the NOAA TIROS series and Russian Meteor series satellites have planned orbital altitudes between 833 and 900 kilometers, a ground station can expect to receive APT signals if these satellites pass through a circular area with a radius of about 3,100 kilometers with the ground station at the center. This area will vary somewhat with the exact attitude of a given satellite but can be used for routine work.

Figure IX-4 is a diagram of the ground station area of reception based on the general orbital parameters of the TIROS polar orbiting satellites and is drawn for a ground station located at approximately 40 degrees north latitude. This diagram, when drawn to scale around the ground station location on the polar map shown in Figure IX-3, will provide information on time of reception, azimuth, elevation, area of image coverage and the length of time the APT

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signal can be expected during any satellite pass. The outermost circle represents the approximate receiving range of the ground station (radius=3,100 kilometers). A satellite passing through this circle can be received with a tracking antenna set at the proper azimuth and 0 degrees of elevation. The inner circles marked 2, 4, 6 and 8 represent the approximate antenna elevations $\times 10$, in degrees, needed to receive a clear signal as the satellite track intersects these circles. The azimuth and elevations obtained from this diagram are approximate but will be generally within

the tolerances of most directional tracking antennas. Omnidirectional antennas do not require tracking but will generally give less area of coverage because of lower signal gain in one particular direction.

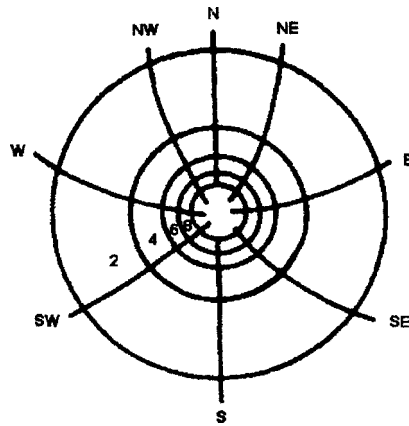


Figure IX-4. Satellite receiving area for a station at 40 degrees latitude

Figure IX-5 shows the tracking materials discussed here arranged for a ground station located at Chambersburg, Pennsylvania. (39.9N / 77.7W) The satellite track positioned for this example shows an ascending node of approximately 63 degrees west longitude which is a typical afternoon orbit for a TIROS series satellite. The actual ascending longitude and time for this orbit would be obtained from the orbital predict data. Table IX-4 gives the tracking procedure for this particular satellite pass.

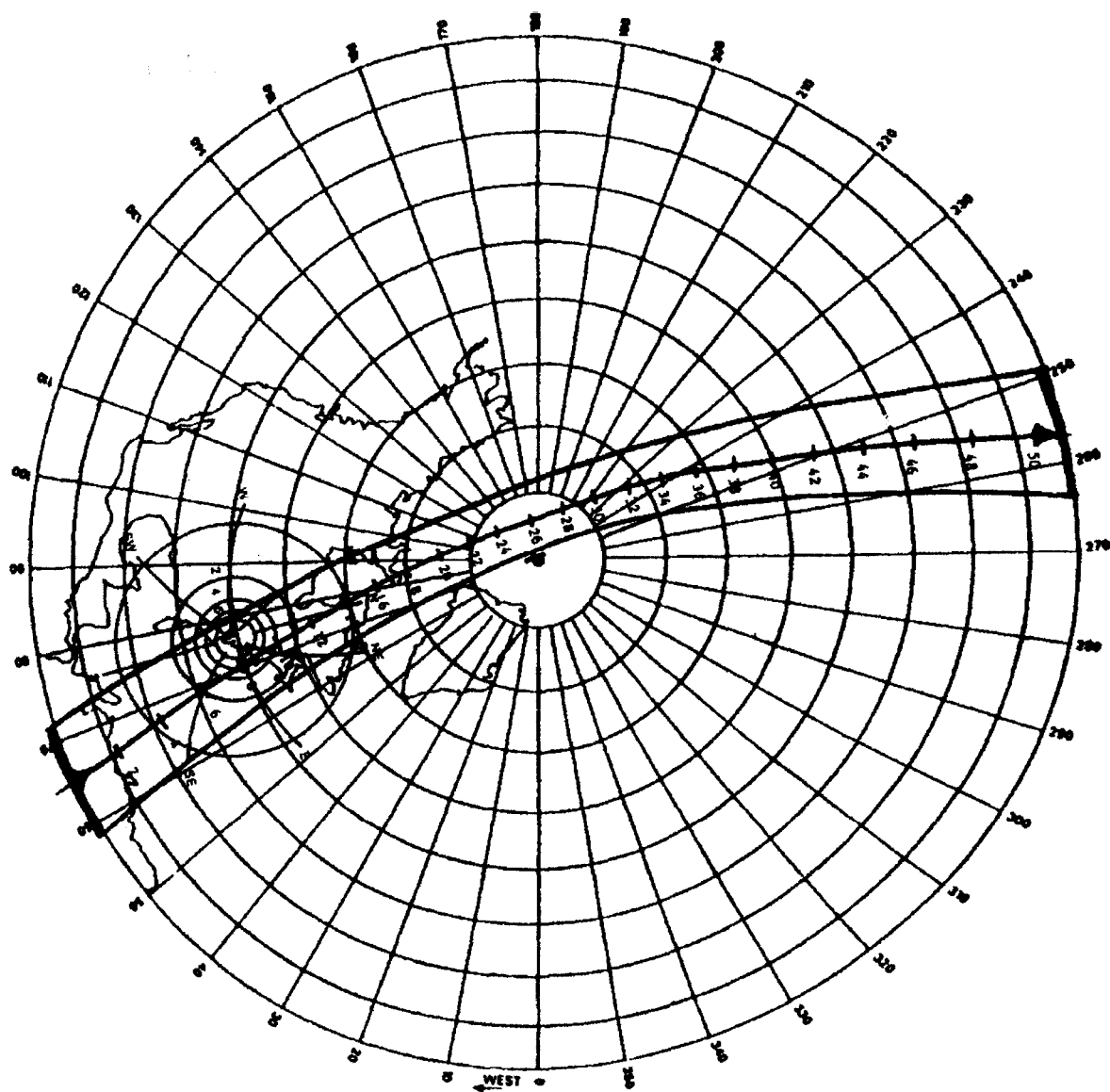


Figure IX-5. Tracking materials arranged for a TIROS-N satellite pass with an ascending node of 63 degrees West, and the receiving station at 39.9N and 77.7W

	ANTENNA AZ/EL	OBSERVATIONS DURING PASS
0	Equator Crossing	No Signal
+4	S/SE, 0 Deg	APT Signal Acquired
+5	S/SE, 10	Haiti, Cuba
+6	SE, 20	Florida
+7	E/SE, 40	Ocean
+8	E, 60	US East Coast
+9	N/NE, 60	Coast

+10	NE, 40	Long Island
+11	N/NE, 20	Lower Great Lakes
+12	N, 10	Great Lakes, Canada
+13	N, 10	Canada
+14	N, 0	Southeast Hudson's Bay
+15	N, 0	Loss of <u>Signal</u>

Table IX-4. Time after **equator crossing, antenna pointing information, and** approximate areas of geographical coverage for the example satellite pass in Figure IX-5

X. THE FUTURE OF DH2ECT READOUT SYSTEMS

During the next ten to twenty years, there will be new series of both polar orbiting and geostationary meteorological satellites launched by the United States, the European consortium (EUMETSAT), Japan and Russia. These satellites will carry improved versions of current instruments or entirely new instruments. The trend is for sensing in additional areas of the electromagnetic spectrum and higher resolutions. This will result in increased amounts of data being transmitted from the satellites, at higher data transmission rates, and the use of data compression techniques to transmit that data within available bandwidth. During this time, there will also be the gradual transition from analog transmissions (as presently used for APT and WEFAX) to digital transmission services.

APT users will get their first look at the future of APT with the launch of the European polar orbiting satellite, METOP-1, now scheduled for 2002. The METOP-1 will not have an analog APT service, but will have Low Resolution Picture Transmission (LRPT). LRPT will be a digital data service, and therefore not compatible with present-day APT systems.

NOAA will continue flying the analog APT system on its satellites through NOAA-N'. According to present schedules, NOAA-N' would likely reach the end of its design life, and be placed in a standby mode around 2010. Prior to that occurring, NOAA will launch the first of the

National Polar Orbiting Satellite System (NPOESS) satellites. NPOESS is the program to combine the civilian NOAA polar orbiters with the Department of Defense DMSP satellites into a single, integrated system. NPOESS will carry a digital LRPT system, and will mark the end of APT on U.S. satellites.

As can be seen by these plans, there will be a considerable period of overlap when both analog APT and digital LRPT will be available to users. There will be a period when METOP and NOAA satellites will be in orbit simultaneously, and a later, shorter period when METOP, NOAA, and NPOESS satellites will be operating simultaneously.

Due to frequency regulations in the 137 - 138 Mhz band, NOAA will change the APT frequencies from the present 137.50 and 137.62 Mhz to 137.10 and 137.9125 NHz with the NOAA-N and NOAA-N' satellites. But this will have far less impact on users than the ultimate change from analog to digital. LRPT will continue to use the same frequencies, and continue to use a right-hand circular polarized transmission for the future NOAA satellites.

While the LRPT receiving system will be more complex, this complexity will be offset by the advantages of more useful data. The number of channels will be increased from the present two, to three. Spatial resolution will be increased from the present average of 4 km to 1 km. Included in the data stream will be data from other spacecraft instruments which will contain information about the vertical and horizontal temperature and moisture structure of the atmosphere.

10-1

The new LRPT digital transmission will be more like the present-day digital HRPT transmission from NOAA satellites. However, LRPT image data will also be compressed, and all the data will be packetized. Hardware will now be required to perform demodulation, bit synchronization (the data rate is expected to be 72,000 bps), frame synchronization and processing the stream of packetized data units to the computer. Computer software will decode, sort and decompress the data the user wants to display.

During the next several years of transition, we will likely see the same technological advances that have produced affordable, high-power desktop computers and ingenuity from amateur enthusiasts and industry that have produced affordable HRPT systems, make available low cost LRPT system components.

The present-day analog WEFAX will also see a transition to the digital realm. NOAA presently plans to have digital Low Rate Image Transmission (LRIT) on the GOES N-Q series of geostationary spacecraft. NOAA plans to launch the first of the new series of GOES satellites, GOES-N, in 2002. There may be a transition period on this series of satellites when both the present analog WEFAX and the digital LRIT services will operate on an alternating schedule from the same spacecraft. EUMETSAT is also developing a new series of geostationary satellites, Meteosat Second Generation (MSG). The first of these satellites is expected to be launched in 2000, and will carry LRIT.

As presently envisioned, the LRIT digital transmission will be a packetized data stream, with a data rate of 128 kbps and a bandwidth of 0.66 Mhz. Similar as to what is done presently, the 10-bit data from the imaging instrument will be truncated to 8-bit resolution. The data will be compressed for transmission.

As these systems come closer to implementation, more details that will be necessary for the developers of ground systems hardware and software, and users, will become available.

XI. ADVANCED APPLICATIONS

APT and WEFAX images provide data for a wide range of studies of the Earth and its atmosphere. Since the imaging instruments on the TIROS and GOES satellites can sample various sections of the electromagnetic spectrum, visible and infrared products are available to ground stations discussed in this publication. The visible images are routinely used to obtain information on cloud cover, location and movement of storms, ice and snow cover, hydrologic data and land features. Infrared images, produced by sampling thermal radiations, provide information used to estimate precipitation, determine storm strength, measure soil moisture, provide for frost warnings, and measure sea and lake surface temperatures.

The application presented in this section is an example of how data from infrared images can more fully be used for quantitative analysis. The temperature calibration techniques for APT images provide basic information needed to obtain accurate temperature measurements using the infrared images transmitted by the TIROS satellites. The use of these techniques can expand the scope of possibilities for using APT data.

DIGITAL TEMPERATURE CALIBRATION TECHNIQUES FOR TIROS APT INFRARED IMAGES

The analog Automatic Picture Transmission (APT) produced by the NOAA polar orbiting satellites is processed AVHRR data containing two images and corresponding calibration and telemetry data. The two images for the APT are selected by ground command from five possible spectral ranges available from the Advanced Very High Resolution Radiometer (AVHRR) imaging instrument. These are:

The APT format is shown in Figure IV-7. Each video line is 0.5 seconds in length, containing two equal segments. Each 0.25 second segment contains:

1. A specific sync pulse
2. Space data with 1-minute timing inserts
3. Earth scan imagery from a selected AVHRR channel
4. A telemetry frame segment



Channel 1: .580-.680 gM (Visible)
Channel 2: .725- 1.10 tM (Near Infrared)
Channel 3: 3.55- 3.93 gM (Thermal Infrared)
Channel 4: 10.3- 11.3 gM (Thermal Infrared)
Channel 5: 11.5- 12.5 gM (Thermal Infrared)

During daylight passes the APT usually contains video from the AVHRR visible channel 1 and infrared channel 4. The space data and telemetry frames, located vertically along either side of the image, both contain information that pertains to that particular AVHRR channel.

The telemetry information is often overlooked by APT users. This is unfortunate because this contains data that can be used to obtain accurate temperature measurements from the thermal infrared images. The use of this data can greatly expand the applications possible for low cost APT stations. Temperature measurements from noise free signals can be made with an accuracy of +/- 2 degrees C using microcomputer techniques now available at many low cost ground stations.

In order to better understand the techniques of APT temperature calibration it is helpful to review the origin of the APT signal produced by the Advanced Very High Resolution Radiometer instruments on the NOAA polar orbiting satellites.

ADVANCED VERY HIGH RESOLUTION RADIOMETER

The AVHRR is the principal Earth imaging instrument operating on the TIROS-N satellites. It is designed to scan with a mirror, rotating at 360 rpm, perpendicular to the direction of the satellite flight. With each rotation of the mirror, data from deep space, an Earth scan, and a warmed black body radiator, which is a part of the instrument housing, are obtained. The radiant energy collected by the mirror is passed through a telescope and then through five separate optical subassemblies to each of five spectral "windows." Each of these detectors has been designed with sensitivity to radiant energy within specific spectral regions of the visible, near-infrared, and infrared spectrum. The three thermal infrared detectors are mounted on a passively cooled mounting called the "patch." This mounting is maintained at a temperature of about 105 degrees Kelvin to assure the proper operation of these infrared detectors.

The analog information from each of the detectors is converted to 10 bit digital samples via an analog to digital converter controlled by a high data rate processor called the Manipulated Information Rate Processor (MIRP). This digital data is then processed by the MW to produce separate data streams that are transmitted by the satellite to ground stations. These data transmissions, previously discussed, are: High Resolution Picture Transmission (HRPT) - real time 1.1 kilometer resolution digital images containing all five spectral channels, and Automatic Picture Transmission (APT) - continuous real time analog transmissions of processed AVHRR data.

APT FROM AVHRR DATA

The analog APT system was designed to produce real time video that can be received and the images reproduced by low cost satellite ground stations. This data stream is produced by the MIRP by amplitude modulating a 2400 Hz subcarrier with the 8 most significant bits of the 10 bit digital AVHRR data. This results in an analog signal with the amplitude varying as a function of the original AVHRR digital image and data. Two of the five possible AVHRR spectral channels are multiplexed so that channel A APT data is obtained from one spectral channel of the first AVHRR scan line and channel B from another spectral channel contained in the second

AVHRR scan line. The third AVHRR scan line is omitted from the APT before the process is repeated. The two spectral channels are determined by ground command. This

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processing results in the APT containing 1/3 of the data from the AVHRR 360 scan lines/minute. The resolution of the APT is, therefore, proportionally reduced and is received at the ground station at a rate of 120 lines per minute of video. During the APT formatting, the MIRP also inserts appropriate calibration and telemetry data for each of the selected images being transmitted. This results in an APT video format as shown in Figure IV-7.

APT ANALOG TO DIGITAL TECHNIQUES

One must begin by determining the calibration and telemetry values within the calibration telemetry wedges. These values must be determined before temperature calibrations are attempted. In the original APT telemetry wedge values are determined by the amplitude of the analog signal and can be measured as voltage levels. This information constitutes a very small segment (10.817 milliseconds per image) of the 0.5 second scan line which makes it difficult to detect and measure without specialized electronic instrumentation often not available to APT users. However, the development of PC based display systems using analog to digital conversion of the APT signal has made it possible to read these telemetry wedges as digital values from the image files. It has been shown that digitized APT offers good-quality quantitative measurements when statistically compared to AVHRR transmission products. (Wannamaker, 1984)

Most PC based image display systems currently use the same basic techniques. That is, they demodulate the signal to remove the 2400 HZ subcarrier, digitize the demodulated signal with an analog to digital converter which reads the voltage changes in a digital format, assigns a user determined color of gray level to the digital value, and displays these as pixel elements of the original APT image on a monitor screen. (See Figure XI-5). The analog to digital conversion done in this process creates an accurate voltage measurement of the APT signal transmitted by the satellite. Basically, this process reverses the original processing done by the MIRP on the spacecraft and reproduces the original 8-bit values used to establish the amplitude modulation of the 2400 Hz carrier. Theoretically, if all systems were error free, the ground station will have recovered the exact digital values of the AVHRR. In practice, the transmission and reception process may add some non-linearity to the signal. This can be corrected by analysis of the values in the telemetry frame.

Although the hardware and software vary considerably from system to system, most software systems allow these digital images to be stored on a diskette as a digital file. In an 8-bit digital system these will be values of 0-255 in an array which is used to create the image on the monitor screen.

If this array contains the IR image from the AVHRR thermal channels 3, 4, or 5 and the corresponding telemetry frames, the user can, with simple software, easily print out portions of the file containing the telemetry information and find the values of the wedges that are needed for the temperature calibrations. The same software can be used to print the digital values found in portions of the IR image. These, then, can be related directly to the original known values of the data transmitted by the NOAA spacecraft. This will provide the necessary information to

complete temperature calibrations for the APT telemetry and to determine temperatures from the digital image.

THE APT TELEMETRY FRAME

The key to temperature calibration of APT infrared channels is in the understanding of the data contained within the space and telemetry frames and the ability to measure these values. Table XI-1 shows the telemetry frame format used in the current NOAA polar orbiting satellites. One complete frame contains 16 individual wedges each of which is composed of eight successive video lines. (One frame = 16 wedges x 8 lines = 128 lines/frame) These frames are continuously repeated during the satellite orbit so that a number of complete frames are

WEDGES 1-8:

```
1 0.757 V MI = 10.6% 2 1.538 V MI = 21.5%
                        3 2.319 V

      MI = 32.4% 4 3.101 V MI = 43.4% 5 3.881 V MI = 54.2%
6 4.663 V MI = 65.2% 7 5.444V
8 6.225 V

      MI = 87.0% ZERO
_ MODULATION_10 THERM TEMP PRT # 1
11 THERM TEMP PRT #2
12 THERM TEMP PRT #3
13 THERM TEMP PRT #4
95
```

APT ANALOG VOLTAGE		DIGITAL VALUE	
		31	
		63	
		127	
		159	
		191	
MI = 76.0%		223	
		255	
14	PATCH TEMP		
15	BACK SCAN		
16	CHANNEL IDENT		
0			

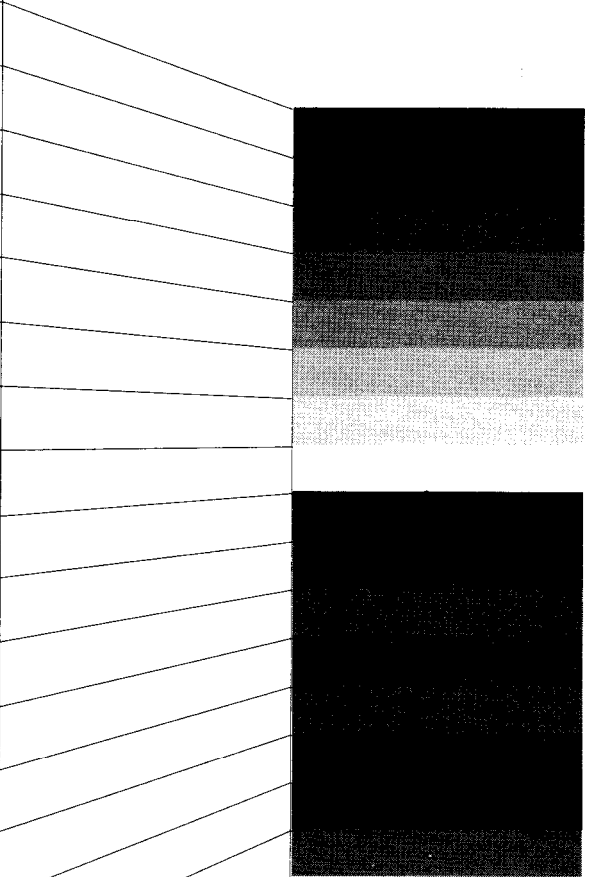


Table XI-1. Telemetry frame format used in TIROS-N series satellite APT

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available at the ground station during one satellite pass. Only one frame is needed for the calibration process. It should be noted that within a telemetry frame the first 15 wedges are identical in both images of the APT format. Only wedges 15 and 16 will be different in channel A and B.

The first eight wedges within one telemetry frame are produced by modulating the 2400 Hz APT subcarrier with 8 linear, 8-bit outputs, from the MIRP on the satellite. The digital values used to modulate each wedge are given in Table XI-1 as "Digital Value." The resulting analog signal received at the ground station is referred to as a "Modulation Index" (MI), and, in the analog domain, will exist as a voltage level for each wedge. A ground station using a black and white display system will see these eight wedges as a gray scale grading from dark gray to near white (MI=10.6% to 87.0%). The graph in Figure XI-1 shows the relationship between the gray levels and the original 8-bit AVHRR output of the MIRP. This linear scale forms the standard APT signal output to which all telemetry data in the remaining wedges can be compared.

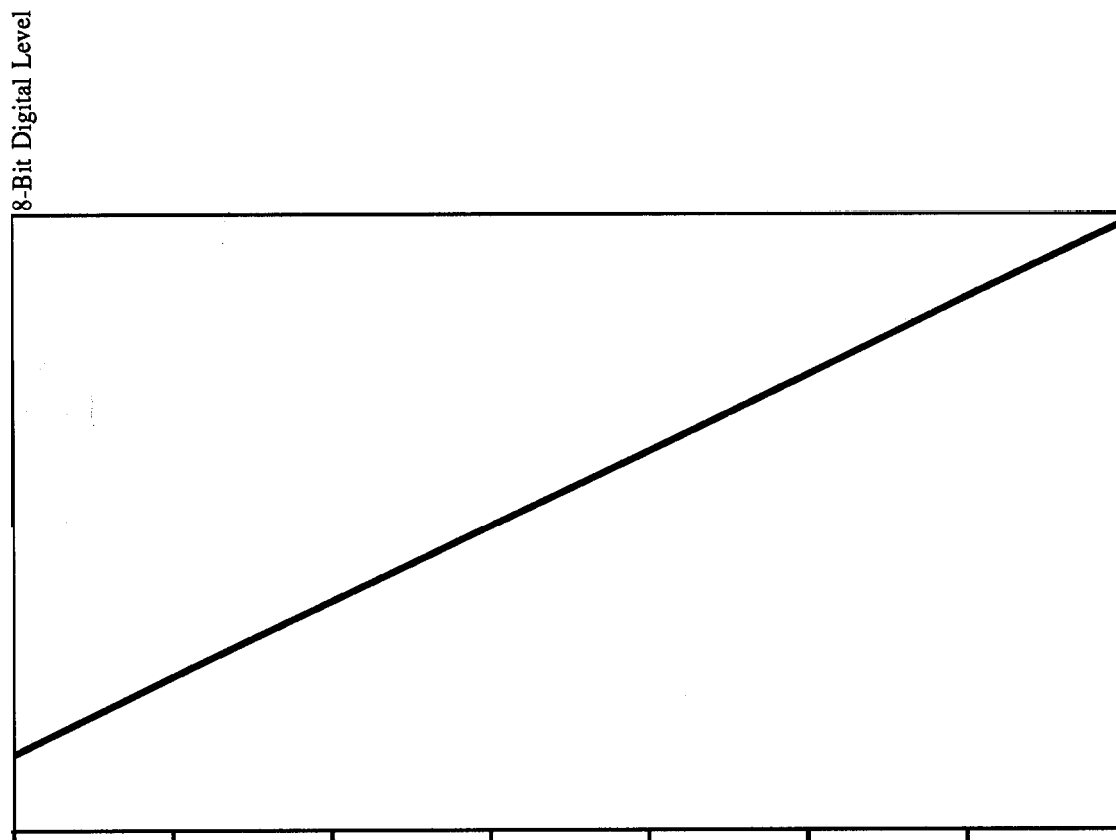


Figure XI-1. Analog/digital telemetry wedge relationship

WEDGE 9: Zero Modulation

The zero modulation wedge contains no signal modulation and represents a base signal level reference. In a black and white display system this wedge will appear black and will have a voltage level of 0 and an 8-bit AVHRR equivalent value of 0.

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WEDGE 10-13: Thermal Temperatures 1-4

During the operation of the AVHRR imaging, the scanner periodically "views" a warmed black body radiator held at approximately 20°C to detect the thermal radiance of that temperature. This "back scan" produces a telemetry response shown in wedge 15. The telemetry in wedges 10- 13 provide the data necessary to determine the actual in-flight temperature of this black body radiator. Four Platinum Resistance Thermometers (PRT's) are mounted on this radiator. The output of each thermometer is monitored as a digital value which then is used to modulate this portion of the APT signal. Temperatures across this heated segment may vary slightly due to differences in temperatures on the satellite. The best estimate of the black body temperature will be obtained from an average of the values contained in wedges 10-13.

The equation to convert voltage of the PRT levels to degrees Kelvin is:

$$\text{Kelvin Degrees} = .206(8\text{-bit value}) + 276.943$$

0 U

.wA4

a x a as

79 00

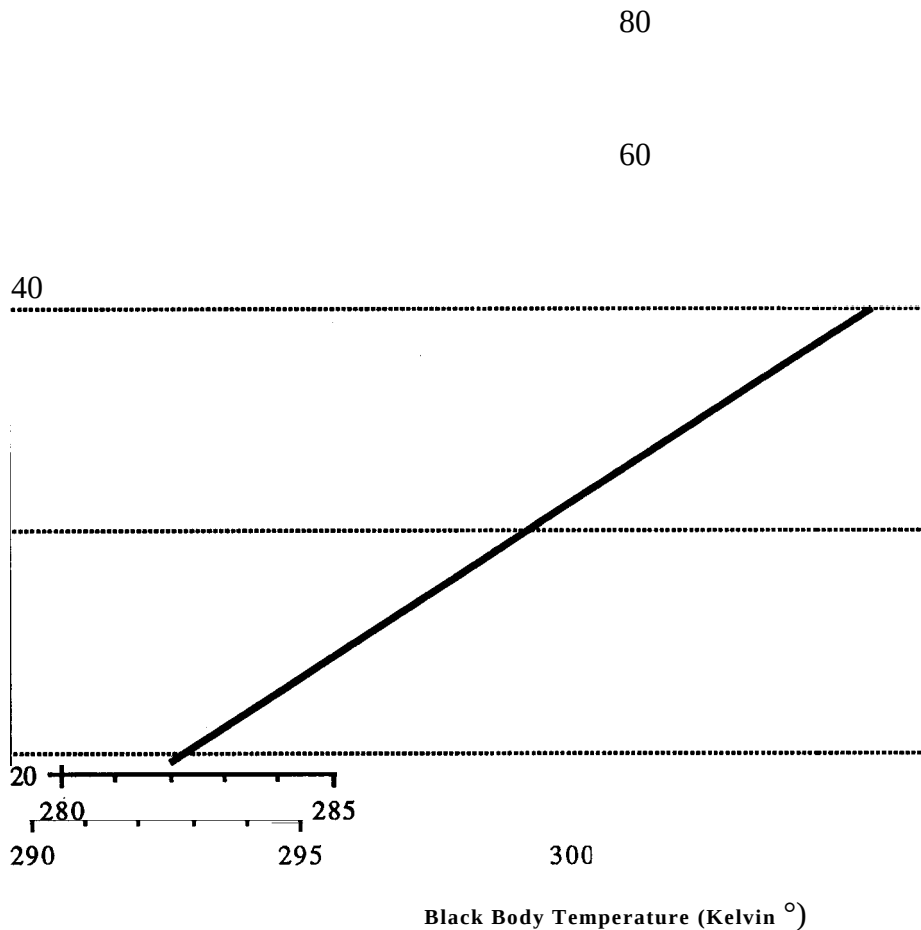


Figure XI-2. Digital black body to temperature relationship

WEDGE 14: Patch Temperature

The patch temperature is a measurement of the temperature of a portion of the AVHRR thermal infrared window mounting that is passively cooled to a temperature of approximately

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105° Kelvin. This temperature is monitored but does not play a direct role in the calibration process discussed here. The equation for converting this value to Kelvin temperature is:

$$K = 124(8\text{-bit AVHRR}) + 90.113$$

WEDGE 15: Back Scan

The back scan is the telemetry value produced when the AVHRR instrument detects the radiance from the black body radiator. This value will vary with each thermal IR channel (AVHRR channels 3, 4, 5) and with slight variations in the temperature of the black body. The response of the AVHRR "look" at the black body is first measured as a digital value which is then used to modulate this portion of the APT signal. Since the value of this data is a measure of the radiance of the black body temperature, which is known from wedges 10-13, this data can be used for in-flight calibration of the spectral channel used to produce the APT IR image. This is done by plotting the measured thermal temperature value against the AVHRR 8-bit value of the back scan to form one point of a temperature calibration curve. A second point can be obtained from the space data, described later.

WEDGE 16: Channel Identification

The channel identification wedge contains information to identify which of the 5 AVHRR channels is being used to produce the APT image. This is done by modulating this portion of the APT signal with a value equal to one of the first 5 gray wedges in the telemetry frame. Therefore, if wedge 16 contains a value equal to wedge 4, AVHRR channel 4 is producing the image seen in the APT video of that channel.

SPACE DATA

Immediately following the sync pulse for each image (See Figure IV-7), the APT video line contains space data. This is a continuous bar that is overwritten with two lines which mark 60 second intervals during the flight of the satellite. The signal level of this data is equal to a value detected by the AVHRR as it views deep space within the spectral range of the IR channel that is presently operational. For temperature calibration purposes this value is considered to have zero radiance for each of the thermal AVHRR channels. This value can then be used to establish a second point for the temperature calibration curve.

WEDGE #1	31	31	30	30	31	30	30	30	WEDGE #9	3	3	3	4	4	5	4	4
	31	30	30	31	31	29	29	30		5	6	5	5	4	5	4	3
	31	32	31	31	32	33	30	29		4	5	5	5	5	4	3	3
	30	30	31	31	29	30	31	29		3	3	3	4	4	4	5	5
	30	30	31	31	30	30	31	31		5	5	4	5	5	5	4	4
WEDGE #2	30	30	29	30	31	30	29	30	WEDGE #10	3	3	3	4	4	4	4	4
	32	32	31	30	31	30	29	29		3	3	3	4	3	3	4	4
	31	31	30	30	30	30	31	31		6	5	5	5	4	4	4	4
	59	59	59	58	58	57	57	58		95	96	94	94	97	96	95	95
	58	58	59	58	58	58	58	59		95	95	97	96	94	93	96	96
WEDGE #3	59	59	58	58	58	56	58	59	WEDGE #11	95	95	95	95	94	94	96	96
	58	58	58	59	57	57	57	58		94	95	97	96	95	95	96	96
	59	59	59	59	57	57	57	57		93	94	96	96	95	95	96	96
	59	58	57	57	60	60	58	57		95	94	94	95	93	95	96	95
	57	57	58	58	58	57	59	58		96	96	95	94	94	95	95	95
WEDGE #4	57	57	59	58	56	57	58	59	WEDGE #12	94	94	95	95	96	96	96	96
	84	84	85	84	83	83	86	87		95	94	93	94	95	96	95	94
	86	86	87	86	85	85	86	86		93	94	96	97	95	95	96	96
	84	84	84	83	82	84	86	85		94	95	94	94	96	97	95	94
	85	84	84	85	83	84	86	85		95	95	95	94	95	94	94	94
WEDGE #5	86	85	86	86	85	85	86	86	WEDGE #13	95	95	93	94	96	96	94	94
	84	84	84	83	83	84	85	86		94	95	95	95	96	95	94	94
	83	83	83	85	84	84	86	86		95	95	94	95	97	96	94	94
	85	85	86	86	84	84	86	86		95	96	93	93	95	95	93	94
	112	112	110	109	110	110	110	110		96	95	93	94	95	95	94	94
WEDGE #6	113	113	ill	ill	113	113	ill	111	WEDGE #14	95	94	93	94	97	96	94	93
	112	ill	109	110	ill	112	111	110		93	94	97	96	94	94	94	95
	113	112	110	109	ill	ill	110	110		94	94	95	95	94	94	94	94
	114	114	ill	ill	113	112	110	110		94	95	94	94	94	94	94	95
	112	112	110	111	114	113	111	111		95	94	93	94	95	95	94	95
WEDGE #7	113	113	ill	112,	114	113	ill	111	WEDGE #15	93	94	95	95	95	94	95	95
	111	ill	110	110	112	111	110	ill		93	93	95	95	94	94	94	95
	136	137	137	138	137	137	137	136		93	94	95	95	94	93	94	95
	138	138	136	136	137	138	135	135		94	93	94	95	94	94	95	95
	138	137	137	138	139	139	136	137		93	93	94	95	95	95	95	94

	137	136	138	138	137	138	139	139		93	93	94	94	94	94	95	95
	135	135	136	137	137	136	137	138		95	95	92	93	96	95	93	93
	137	137	139	139	137	136	137	138		96	95	93	92	95	95	93	94
	135	135	137	138	136	136	138	138		93	93	96	96	93	93	95	95
	134	135	138	138	136	137	139	138		93	94	97	95	93	94	95	95
WEDGE #6	161	162	165	165	162	161	164	165	WEDGE #14	89	88	90	90	89	89	90	89
	161	162	165	165	162	162	164	164		88	89	91	90	88	89	90	89
	165	164	162	162	164	163	161	162		88	88	89	90	89	90	90	90
	161	162	165	164	162	162	164	163		89	89	90	90	89	90	90	90
	162	162	165	164	161	161	164	164		89	89	90	89	88	88	90	90
	162	163	165	165	163	163	164	164		89	90	90	89	89	90	89	89
	163	163	164	163	162	163	162	163		90	89	88	90	91	90	90	89
	163	163	164	164	162	163	163	163		89	89	90	90	90	90	90	89
WEDGE #7	188	189	189	188	187	188	189	188	WEDGE #15	61	61	61	60	61	61	60	61
	190	191	190	188	188	189	188	187		61	61	60	61	61	62	61	61
	188	190	190	189	189	190	189	188		61	62	62	61	62	61	61	61
	187	186	189	190	187	188	191	192		62	61	60	60	62	62	60	60
	188	188	191	191	187	187	190	191		61	62	61	61	61	61	60	60
	190	192	188	187	190	190	187	188		62	62	61	60	62	62	61	60
	191	191	188	188	190	190	187	187		63	62	61	61	61	61	61	60
	191	192	188	188	190	191	188	188		61	62	62	62	61	62	62	62
WEDGE #8	217	217	214	213	216	216	212	212	WEDGE #16	110	ill	113	112	110	ill	114	113
	217	218	213	212	215	215	213	214		112	112	ill	112	112	112	ill	111
	217	216	212	213	216	216	212	212		113	113	110	111	114	113	111	ill
	217	216	211	212	215	215	212	213		113	113	111	110	113	113	ill	ill
	216	217	213	213	216	215	212	213		112	113	112	112	112	112	ill	111
	213	213	215	214	213	215	218	216		113	112	ill	ill	113	112	111	ill
	214	214	215	214	213	215	216	215		112	111	112	112	112	111	ill	112
	215	215	213	214	216	215	213	214		113	ill	111	112	113	112	ill	ill
				SPACE		211	211	206 206		211	210	208	209	211	211	206	206
				DATA		211	212	207 207		211	211	208	208	211	211	206	206
						211	211	206 207		211	210	208	208	210	211	207	207
						211	209	205 207		212	212	208	209	212	211	206	206

Table X1-2. Digital value printout from one 16 wedge telemetry frame

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DIGITAL APT IR TEMPERATURE TECHNIQUES

Table XI-2 shows a printout of the digital values taken from one 16-wedge telemetry frame of channel 4 IR APT data. NOTE: The IR channel identification can be done by observing the digital value of wedge 16 and comparing it with the first 8 telemetry wedges. In this example, wedge 16 matches wedge 4 indicating channel 4 IR is being transmitted via the APT. A small segment of space data is also included. In this example, the analog APT was digitized using an IBM interfacing system developed by GTI Electronics and Softworks, Inc. The image was received, digitized and stored as a digital text file using the GTI system. One noise free telemetry frame and segment of space data were then selected from this image file and printed.

Since a variety of factors cause variation of the digital values within the data, an average was taken as the best estimate for each wedge and the space data. These averages, with their standard deviations to show the amount of variation within the data, are shown in Table XI-3.

WEDGE NUMBER	MEAN DIGITAL VALUE	STANDARD DEVIATION
1	30.39	0.865
2	57.98	0.899
3	84.77	1.178
4	111.31	1.310
5	137.03	1.221
6	163.08	1.276

7	188.95	1.516
8	214.42	1.753
9	4.09	0.830
10	95.14	0.960
11	94.71	0.990
12	94.30	0.890
13	94.17	1.090
14	89.37	0.760
15	61.17	0.720
16	111.78	0.970
SPACE	209.80	2.189

Table XI-3. Statistical analysis of an APT digital telemetry frame

To calibrate the digital values received at the ground station to real temperatures, a relationship must first be established between these station counts (SC) and the original AVHRR 8-bit linear values used by the spacecraft electronics to establish the analog APT signal. This can be done, using standard statistical techniques of correlation and regression analysis. Determining the correlation between the APT station counts and the original AVHRR digital

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values will show how well the station counts will reflect the AVHRR counts and regression analysis will provide the necessary equation that can give the best estimate of the AVHRR data based on the station counts. Both of these analyses are not difficult but they do require rather laborious calculations. Fortunately, a number of pocket calculators perform these mathematical processes and a variety of statistical software packages for microcomputers are available to do both correlation and regression analysis. Additional information concerning these techniques can be found in any basic statistics book.

CALIBRATION STEPS

STEP 1

To determine if there is a statistically significant correlation between the station count data shown in Table XI-3 and the standard AVHRR 8-bit digital values the following equation for correlation can be used:

$$r = \frac{n \sum XY - \sum X \sum Y}{\sqrt{[n \sum X^2 - (\sum X)^2][n \sum Y^2 - (\sum Y)^2]}}$$

Where X= AVHRR values

and Y= Station count averages in Table XI-3

X_ _Y

31	30.39
63	57.98
95	84.77
127	111.31
159	137.03
191	163.08
223	188.95
255	214.42

$$r = \frac{[8(176532.4)] - [(1144)(987.93)]}{\sqrt{[8(206600) - (1144)^2][8(150911.4 - 976005.68)]}}$$

$$r = .99$$

When using 8 pairs of data, r values between .66 and 1.0 are considered to be significantly correlated within a 95% confidence level. The correlation value (r=.99) in this example indicates that the station counts and the AVHRR data are significantly correlated and will be good predictors of the original AVHRR values established on the spacecraft.

STEP 2

If the relationship between the station counts and the AVHRR values show significant linear correlation, an equation to estimate the AVHRR counts from the station counts can be calculated by regression analysis using the following equation:

$$Y = BX + A$$

Where Y = Station Counts,

and X = AVHRR Counts

and

$$A = \frac{\sum Y - B \sum X}{n}$$

$$B = \frac{\sum XY - \frac{(\sum X)(\sum Y)}{n}}{\sum X^2 - \frac{(\sum X)^2}{n}}$$

$$B = \frac{[8(176533.35)] - [(1144)(987.93)]}{[8(206600)] - (1308736)}$$

In this example:

$$B = \frac{[8(176533.35)] - [(1144)(987.93)]}{[8(206600)] - (1308736)}$$

$$B = 0.8198$$

and

$$A = \frac{987.93 - [(0.8198)(1144)]}{8}$$

$$A = 6.25$$

Therefore, from $Y = BX + A$, the best estimate of AVHRR data from station counts is:

$$Y = .8198X + 6.25$$

$$\text{or, } X = \frac{Y - 6.25}{.8198} \text{ or } AVHRR = \frac{\text{StationCounts} - 6.25}{.8198}$$

STEP 3

To establish a digital to temperature conversion scale on the graph in Figure XI-4, three telemetry values must be established from the data contained in the telemetry frames and space data:

1. The data reported in telemetry wedges 10, 11, 12, and 13 that monitor the temperature of the black body radiator
2. The AVHRR digital equivalent of the back scan data in wedge 15
3. The AVHRR digital equivalent value contained in the space data

BLACK BODY TEMPERATURE:

The actual temperature of the black body can be determined by averaging the station counts in wedges 10 through 13 to get the best estimate of this data. This average station count value can then be converted to the AVHRR equivalent using the regression equation in step 2. This AVHRR count can then be converted to degrees Kelvin using the equation:

$$\text{Black Body Temperature} = .206(\text{AVHRR count}) + 276.943$$

In this example:

$$\text{Average station counts (wedges 10-13)} = 94.58$$

$$\text{AVHRR equivalent value} = 107.74$$

$$\text{Temperature} = .206(107.74) + 276.943$$

$$\text{Temperature (K)} = 299.14$$

BACK SCAN DATA:

The back scan data contained in wedge 15 must also be converted to an AVHRR equivalent value using the regression equation from step 2. In this example:

$$\text{Back scan station count average} = 61.17$$

$$\text{AVHRR equivalent} = 66.99$$

The average temperature of the Black Body radiator as reported by the four Platinum Resistance Thermometers (299.14° K) and the digital response of the Advanced High Resolution Radiometer when it views the Black Body (66.99) from one point of the temperature calibration

curve on the graph in Figure XI-4. This is done by plotting the digital value of the back scan (X axis) against the temperature of the black body (299.14°K) on the Y axis.

SPACE DATA:

A second point is plotted using the space data. In this example the average station count of the space data was 209.8 as seen in Table XI-2. Using the regression equation from step 2, the AVHRR equivalent value is calculated to be 248.41. The bottom line on this graph represents a nominal radiance of zero, corresponding to a theoretical temperature of 0 degrees Kelvin. When these two values, 248.41 plotted on the X axis and 0° K on the Y axis, they form a second point of the calibration curve in Figure XI-3. A line drawn through these two points represents a calibrated linear correlation between the instrument observed radiance and the digital station counts. At this point, the digital values of the IR image can be converted to temperatures using the regression equation that was determined in step 2 and the calibration graph Figure XI-3.

NOTE: This process requires that the original signal level, during the analog to digital conversion, not exceed the 255 digital level. This would drive the near white (cold temperatures) digital values to saturation and would result in a loss of this data and an inaccurate calibration of all of the image data. This can be controlled by establishing the proper volume of the radio receiver when the satellite signal is acquired and digitized.

Y v W Q L
Q w a

W 1
320

310

290

280 270 260

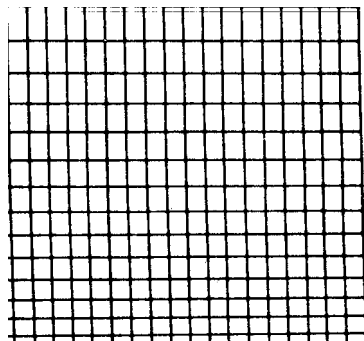
250 240

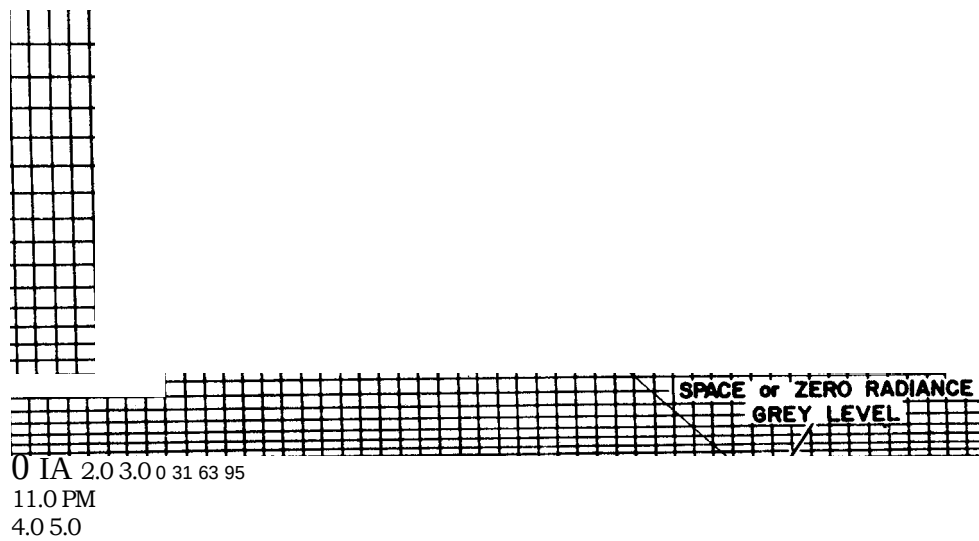
230 220 210 200 180 130

111111111 111111111 111⁰111111



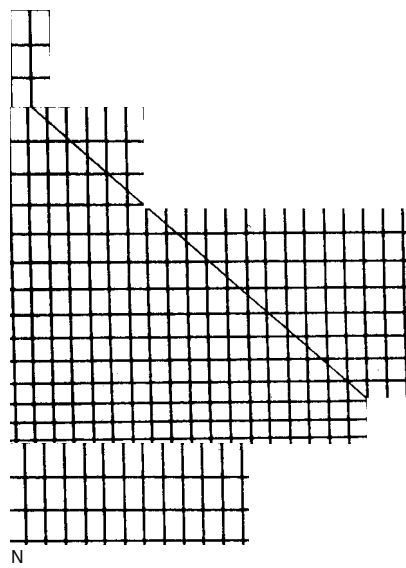
•1•1111111`11111•1111111111111H111111111111•11•111





127 159

a



6.0 191
70 8.0 223 255

Figure XI-3. **Calibrated digital-to-temperature relationship of APT channel 4 IR image**

APPENDIX A. GLOSSARY

albedo	Same as reflectivity. Expressed as the percent of visible radiation reflected from a surface.
Amplitude modulation	AM- the strength (amplitude) of a signal is varied (modulated) to correspond to the information to be transmitted. As applied to APT, an audible tone of 2400 Hz is amplitude modulated, with maximum signal corresponding to light areas of the photograph, the minimum levels black, and intermediate strengths the various shades of gray.
analog	A system of transmitting and receiving information in which one value (i.e. voltage, current, resistance, or, in the APT system, the volume level of the video tone) can be directly compared to the information (in the APT system, the white, black, and gray values in the photograph).
apogee	The point in a satellite's orbit farthest from the Earth.
APT	Automatic Picture Transmission. A function of polar orbiting weather satellites which transmits earth scan photographs to direct readout stations in real time in an analog video format. Transmission consists of an amplitude modulated audible tone which can be converted to photographs when fed to an appropriate line printing device.
Argument of perigee	Number of degrees from the ascending node where perigee occurs.
Ascending node	Intersection of a satellite's orbital plane with the Earth's equatorial plane.
AVHRR	Advanced Very High Resolution Radiometer. Sensor on board NOAA polar orbiters (part of the TIROS series of satellites) which senses passive radiation emitted from Earth and its atmosphere.
azimuth	Angle measured in the horizontal plane from true North to target.
bandwidth	In FM, radio frequency signal bandwidth is the amount of deviation of the signal.
blackbody	A perfect radiator and absorber of electromagnetic energy. A blackbody has an emissivity of 1, and its NOAA IR channel temperature will be equivalent to its actual temperature.
carrier	in radio, an rf frequency capable of being modulated with some type of information.

circularly polarized rf	Radio frequency transmissions where the wave energy is divided equally between a vertically polarized and a horizontally polarized component.
dB (db)	decibel-the unit of measuring the intensity of a sound expressed as a ratio to a reference level. The decibel is also used to measure relative strengths of antenna and amplified signals and always refers to a ratio or difference between two values.
Descending node	The portion of a polar orbiting satellite's orbit which passes over the earth from north to south
DMSP	Defense Meteorological Satellite Program
Doppler effect	If an electromagnetic source moves relative to an observer, there is a shift in the observed frequency. Also known as Red Shift, if the source is receding from the observer, the observed frequency will appear to decrease.
dropout	The loss of data from one or more scan lines.
eccentricity	Description of the shape of a satellite's orbit. A circular orbit has an eccentricity of 0.0, the closer to 1.0 the eccentricity, the more elliptical an orbit is. Most artificial satellite orbits have an eccentricity less than 0.01, essentially circular.
ecliptic	The great circle around the sky on which the sun appears to move through the year as the earth rotates around it. The ecliptic plane is the plane of the earth's orbit. The orbit's of the other planets also lie close to this plane.
elevation	Angle above the horizon
emissivity	The ratio of energy emitted by a material to that which would be emitted by a blackbody at the same temperature.
epoch	Year, Month, Day of orbital elements.
equatorial plane	An imaginary plane through the center of the Earth and the Earth's equator.
(FAX)	A process where graphic or photographic information is transmitted or recorded by electronic means.
Field of View	Essentially the synthesis of the IFOV from the scanning process of the radiometer.

frequency modulation	FM-the frequency of a transmission signal is varied (modulated) from a given center frequency to correspond to the information to be transmitted. As applied to APT, the radio signal from the satellite is broadcast on an FM band of the radio spectrum, requiring an FM radio receiver for proper reception.
GAC	Global Area Coverage. Recorded HRPT data at low resolution (4 km).
Geostationary orbit	An orbit whose period equals the rotation period of the Earth. Artificial satellites are usually placed in geosynchronous orbit at 35,800 km altitude.
GMS	Geostationary Meteorological Satellite. Specifically, a Japanese satellite.
GMT	Greenwich Mean Time, also known as Zulu time or UTC (Coordinated Universal Time), it is the local time at Greenwich Observatory, England (0 degrees longitude).
GOES	Geostationary Operational Environmental Satellite. Specifically, a United States satellite.
GVAR	GOES VARiable. The processed instrument data format for GOES I-M.
Hertz-MHz-KHz:	Hertz is the unit of measuring the frequency of any radiated signal. One Hertz equals one cycle per second. Radio frequencies are expressed in the decimal multiples of Megahertz (1,000,000 cycles) and Kilohertz (1,000 cycles).
FURS	High Resolution Infrared Radiation Sounder, a TIROS instrument.
HRPT	High Resolution Picture Transmission. A telemetry from the NOAA TIROS-N satellites.
IC	Integrated circuit-a solid state electronic circuit which consists of several micro components constructed to perform a special function.
IFOV	Instantaneous Field of View. The solid angle through which a detector is sensitive to radiation. It forms one limit to the resolution of an imaging system.
inclination	The angle between the orbit plane and the Earth's equatorial plane, measured counter-clockwise. A zero inclination orbit would mean the satellite is orbiting directly over the equator, an inclination of 90 degrees is a perfectly polar orbit.
IR	Infrared.
Kbps	Kilobits per second.

kilometer	Metric unit of distance equal to 3,280.8 feet or .621 miles.
LAC	Local Area Coverage, HRPT data recorded at high resolution (1.1 km).
Mean anomaly	Represents the angular distance from the perigee point to the satellites mean position. Measured in degrees along the orbital plane in the direction of motion.
mean motion	Number of complete revolutions the satellite makes in one day.
Mbps	Megabits per second.
Meteor	The Soviet Union's series of polar orbiting weather satellites. The Meteor satellites transmit imagery in a system compatible with the NOAA TIROS satellites.
METEOSAT Meteorological Satellite. Specifically, a European satellite.	
MHz	Megahertz-see Hertz.
MSU	Microwave Sounding Unit, a TIROS instrument.
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
nadir	The point on the ground vertically beneath the satellite.
NESDIS	National Environmental Satellite Data and Information Service, a component of NOAA.
OLS	Operational Line Scanner, a DMSP satellite instrument.
Orbital elements	A collection of quantities that, together, describe the size, shape, and orientation of an orbit.
PDUS	Primary Data User Stations consisting of mainly a ground station and an image processing system. Refers to those stations receiving data directly from the satellite (such as GVAR data) versus preprocessed data (such as WEFAX).
perigee	The point in a satellite's orbit where it is closest to the Earth.
POES	Polar Operational Environmental Satellite
polar orbit	An orbit whose path crosses near the poles.

reflectivity	Same as albedo. Expressed as the percent of visible radiation reflected from a surface.
retrograde	Satellite orbit motion which is opposite to the Earth's direction of rotation, also defined as an orbit with an inclination greater than 90 degrees
right ascension of ascending node	The angular distance from the vernal equinox measured eastward in the equatorial plane to the point of intersection of the orbit plane where the satellite crosses the equatorial plane on the ascending node.
SAR	Synthetic Aperture Radar. Also, Search And Rescue
SBUV	Solar Backscattered Ultraviolet system. A TIROS instrument.
SEM	Space Environment Monitor. An instrument found aboard both TIROS and GOES satellites.
shimmer	An effect produced by the movement of masses of air with differing refractive indices. Shimmer results in the blurring of remote sensed images, and is the ultimate limiting factor over the resolution.
SDUS	Secondary Data User Station. A ground receiving station capable of receiving preprocessed satellite imagery (and other imagery), typically referring to WEFAX user stations.
SSM/I	Special Sensor Microwave Imager. A DMSP satellite instrument.
SSM/TI	Special Sensor Microwave Temperature sounder on board the DMSP satellites
SSM/T2	Special Sensor Microwave water vapor profiler on board the DMSP satellites.
SST	Sea Surface Temperature.
SSU	Stratospheric Sounding Unit. A TIROS instrument.
Sun synchronous	describes the orbit of a satellite which provides consistent lighting of the earth scan view. The satellite passes the equator and each latitude at the same time each day. For example, a satellite's sun-synchronous orbit would cross the equator twelve times a day, each time at 3:00 P.M. local time. The orbital plan of a sun-synchronous orbit must also precess (rotate) approximately one degree each day to keep pace with the earth's surface.

TIROS	Television Infrared Operational System. A series of meteorological satellites operated by NOAA.
TOVS	TIROS Operational Vertical Sounder. A suite of instruments aboard TIROS comprised of the HIRS, MSU and SSU.
VISSR	Visible Infrared Spin-Scan Radiometer. The primary imaging instrument aboard the GOES satellites through GOES-7.
WEFAX	Weather Facsimile. An analog data transmission service from the GOES satellites.
yagi	a type of receiving antenna which has several rod elements mounted on a beam. Its directional pattern of sensitivity and ease of construction make it ideal for APT direct readout stations.

APPENDIX B. INFORMATION RESOURCES

Orbital elements for operating meteorological satellites, in the form of two-line elements (TLEs), monthly predictions and/or TBUS messages can be found on the following bulletin boards (BBS) or Internet sites:

NOAASIS web site, <http://140.90.207.25:8080/noaasis.html> Celestial web site, <http://www.grove.net/~tkelso>

Canada: SpaceBase BBS (+1) 604 473-9357 Italy: Trance BBS: (+39) 11482 751
United Kingdom: Starbase One BBS (+44) 0171 701 6914 or 0171 703 3593 United Kingdom:
RIG BBS (+44) 01344 874140
United Kingdom: Timestep BBS (+44) 01440 820002 USA: DRIG BBS (+1) 214 492-7057
USA: OIG BBS (+1) 301262-6748

USA: SAT TRAKERS BBS (+1) 714 590-4382 USA: SSC BBS (+1) 619 259-5554
USA: Western Pacific BBS (+1) 415 453-2854

Copies of the current GOES-EAST or GOES-WEST WEFAX transmission schedule can be obtained by writing to address (1) below, or on the NOAASIS web site.

A list of manufacturers and suppliers of complete weather satellite receiving systems and components is available. This "Manufacturers List" can be requested from address (1) below, or can be found on the NOAASIS web site.

The NOAASIS web site (<http://140.90.207.25:8080/noaasis.html>) is operated by NOAA/NESDIS Direct Services Division, and contains extensive information related to the NOAA TIROS and GOES satellites. The NOAASIS web site also contains links to sources of information for other meteorological/environmental satellites and related areas of interest to satellite direct readout users.

Information about the European METEOSAT and METOP satellites, and their operations can be found on the EUMETSAT web site, <http://www.eumetsat.de>.

Addresses

(1) Direct Readout Coordinator NOAA/NESDIS Direct Services Division E/SP3 4700 Silver Hill Road, FB-4
Stop 9909
Washington, DC 20233-9909
Telephone: 1301457-5678 FAX: 1301568-8649 [E-mail: satinfo@nesdis.noaa.gov](mailto:satinfo@nesdis.noaa.gov)

For information about the Search And Rescue program utilizing the NOAA GOES and TIROS satellites, contact:

(2) SARSAT Coordinator
NOAA/NESDIS Direct Services Division E/SP3 4700 Silver Hill Road, FB-4
Stop 9909
Washington, DC 20233-9909
Telephone: 1301457-5678 FAX: 1301568-8649

For information about, and requirements to use the GOES Data Collection System (DCS) contact:

(3) DCS Coordinator

NOAAJNESDIS Direct Services Division E/SP3 4700 Silver Hill Road, FB-4

Stop 9909

Washington, DC 20233-9909

Telephone: 1301457-5678 FAX: 1301568-8649

The following **Internet** sites are suggested as places to find more information about getting started in satellite direct readout activities and general information about meteorological/environmental satellites:

- www.mmm.ucar.edu/pm/satellite/satellite.html • www.amsat.org/amsat/keps/kepmodel.html
- www.rig.org.uk • www.drig.com spacelink.nasa.gov/. index. Html
- climate.gsfc.nasa.gov/-chesters/goesproject.html • www.wmo.ch/hinsman/satsun.html

APPENDIX C. GROUND STATION USER'S SURVEY

The National Environmental Satellite, Data, and Information Service (NESDIS) manages the United States' civil Earth-observing satellite systems. In an effort to better serve the user community of NOAA-operated and other environmental satellites, NESDIS maintains a "users list" of all known environmental satellite readout stations throughout the world.

The users list is one way NESDIS has of keeping the user community informed of changes to satellite operations, establishing how direct readout data is being used, and planning future satellite capabilities and programs. NESDIS also provides limited information about satellite station location and type of data received only, to the World Meteorological Organization (WMO).

When establishing a new satellite receiving station, or modifying or relocating an established station, NESDIS requests the station operator's cooperation by completing the questionnaire (or a copy) on the following page, and returning to NESDIS.

Your response is voluntary and all information is handled in accordance with the United States Privacy Act.

The completed questionnaire can be mailed to the following postal address:

NOAA/NESDIS E/SP3
Direct Services Division
Attn: W. Winston
4700 Silver Hill Road, Stop 9909
Washington, DC 20233-9909 USA

Questionnaires may also be faxed to: 1301-568-8649. An on-line version of the survey is also available for completion at the NOAASIS web site.

If you have any questions about this survey or any aspect of the NOAA satellite program, please contact the Data Services Team at the above address or facsimile number.

NOAA SATELLITE GROUND STATION CUSTOMER QUESTIONNAIRE (OMB AUTHORIZATION NO. 048-0227 EXPIRES 09/30/98)

Directions. Thank you for taking the time to complete this questionnaire. Please answer all questions that apply. Most questions will require only one response.

Check one user category which best describes your activity.

Amateur

Commercial / Business

Equipment or software manufacturer Government meteorological organization
Other civil government
Military

High School, Technical School Television or Radio broadcast station
University or College
Other - please describe.
(see la.)
or Elementary School

la. If an equipment or software manufacturer, check all products or services that apply:

APT HRPT GOES-TAP WE FAX Other - please list.

VISSR/VAS/GVAR (GOES, METEOSAT, GMS, etc.) Software

Image interpretation services Complete "turn key" installations

2. Do you receive environmental, meteorological satellite transmissions?

Yes

No Not applicable

2a. If you answered yes, please indicate one category which best describes how often you receive satellite transmissions.

Daily

Several times per month Other - please describe.

Several times per week

3. What data types do you receive? Check all that apply (from any satellite(NOAA, METEOR, GOES, GMS, METEOSAT, GOMS, INSAT, etc.):

APT Automatic Picture transmission (NOAA, METEOR, etc.) HRPT High

Resolution Picture Transmission

WEFAX (GOES, METEOSAT SDUS, GMS, etc.) 1691Mhz services

GOES VISSR/GVAR, METEOSAT PDUS, GMS, GOMS, INSAT etc. direct high resolution transmission service

DSB Direct Sounder Broadcast (TOVS, MSU, SSU, etc.) Other - please specify.

Do not know / Not applicable

4. Do you have access to any of the following? Check all that apply.

Computer with modem

Electronic mail (E-mail) Internet Commercial on-line service (CompuServe, MCINet, or similar) Do not know / Not applicable

5. Do you obtain navigation/orbital predict information directly from NOAA via the NOAA.SIS or NOAA.SIS Web site?

Yes - No - Do not know / Not applicable

6. What is the location of your receiving station? Latitude (North or South?) Longitude (East or West?)

Do not know / Not applicable

7. User information: Please fill out completely. Please print or type.
Name: Title: Organization: Division: Address: Country: Telephone: TeleFax:
Email:

Please return completed survey to:

NOAA Satellite Questionnaire NOAA/NESDIS

Direct Services Division E/SP3 4700 Silver Hill Road, Stop 9909 Washington, DC 20233-9909

USA or FAX to 301 568-8649

Public reporting burden for this collection of information is estimated to average 10 minutes per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to NOAA/NESDIS E/SP3, 4700 Silver Hill Road, Stop 9909, Washington, DC 20233-9909. NOAA may not conduct, nor are you required to respond to, this collection of information unless a currently valid OMB control number appears on this form.

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established as part of the Department of Commerce on October 3, 1970. The mission responsibilities of NOAA are to assess the socioeconomic impact of natural and technological changes in the environment and to monitor and predict the state of the solid Earth, the oceans and their living resources, the atmosphere, and the space environment of the Earth.

The major components of NOAA regularly produce various types of scientific and technical information in the following kinds of publications:

PROFESSIONAL PAPERS - Important definitive research results, major techniques, and special investigations.

CONTRACT AND GRANT REPORTS - Reports prepared by contractors or grantees under NOAA sponsorship.

ATLAS - Presentation of analyzed data generally in the form of maps showing distribution of rainfall, chemical and physical conditions of oceans and atmosphere, distribution of fishes and marine mammals, ionospheric conditions, etc.

TECHNICAL SERVICE PUBLICATIONS - Reports containing data, observations, instructions, etc. A partial listing includes data serials; prediction and outlook periodicals; technical manuals, training papers, planning reports, and information serials; and miscellaneous technical publications.

TECHNICAL REPORTS - Journal quality with extensive details, mathematical developments, or data listings.

TECHNICAL MEMORANDUMS - Reports of preliminary, partial, or negative research or technology results, interim instructions, and the like.



**U.S. DEPARTMENT OF COMMERCE National Oceanic and
Atmospheric Administration** National Environmental Satellite,
Data, and Information Service Washington, D.C. 20233